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DR. J. OBEREGGER

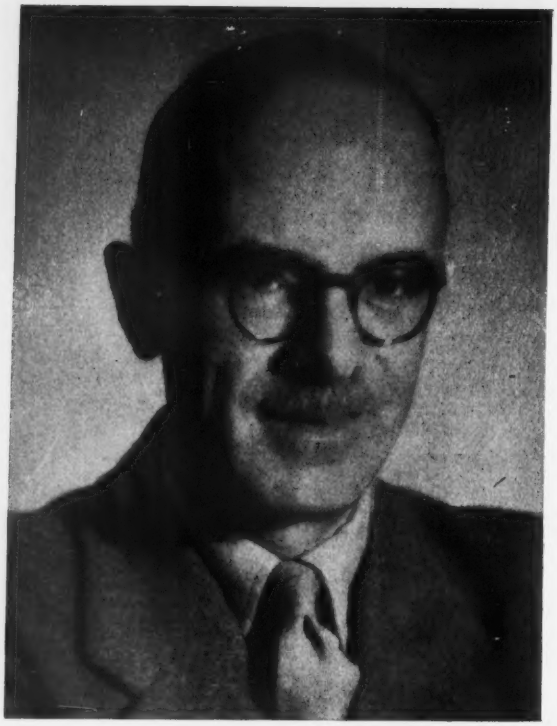
JOSEPH OBEREGGER, General Manager of the Oesterreichisch-Alpine Montangesellschaft, was born in 1896, in Leoben. He was educated at the Secondary School in Leoben and, after a period of army service during the First World War, he continued his technical studies at the Montanistische Hochschule, graduating as Dipl. Ing.

He joined the staff of the Oesterreichisch-Alpine Montangesellschaft in 1922, and, apart from the period of the Second World War when he was placed in a concentration camp, he has spent all his working life in the service of the Company. He has been successively Blast-Furnace Manager, Federal Commissioner (1934), Technical Director (1936), and General Manager (1945). While he was Technical Director he was awarded the honorary title of Bergrat by the President of the Austrian Republic in recognition of his services to the Country.

On the occasion of the celebration of the centenary of the Montanistische Hochschule, Leoben, in 1949, Dr. Oberegger was awarded the Honorary Degree of Dr. mont., at the same time as Dr. C. H. Desch (Past-President of The Iron and Steel Institute) and Dr. R. Durrer (Honorary Vice-President).

As well as being President of the Federation of Mining and Iron and Steel Producing Industries in Austria, Dr. Oberegger became President of the Austrian Iron and Steel Institute (Eisenhütte Oesterreich) when it was re-inaugurated in February, 1950.

In connection with the Special Meeting of The Iron and Steel Institute to be held in Austria, Dr. Oberegger has kindly consented to be Chairman of the Austrian Reception Committee.



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Professor Dr. R. Walzel

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Use of Oxygen/Carbon Dioxide instead of Air in the Final Stage of the Basic Bessemer Process

By Bo Kalling, Folke Johansson, and Lennart Lindskog

SYNOPSIS

The paper describes the results of a number of experimental blows in a 14-ton basic Bessemer converter at Domnarfvet Iron Works, in which the charges were dephosphorized with O_2/CO_2 instead of air in order to reduce the nitrogen content of the product. It was reduced to about 0·006% in the finished steel, as against about 0·012% by normal air blows. A further reduction to 0·003–0·004% was found to be possible by using oxygenated air for the preliminary blowing. Equal parts of oxygen and carbon dioxide produced approximately the same temperature conditions as air-blowing but the blowing time was slightly shortened. There was no apparent increased injury to the converter bottom. The gas consumption was about 1200 cu. ft. per metric ton of pig iron, which at a price of 2s. per 1000 cu. ft. corresponds to 2·4s. per ton.

Another advantage of the final blowing with O_2/CO_2 was that the pouring temperature could be adjusted to whatever was most suitable for the mode of pouring and the quality of the steel. By using more than about 50% of oxygen in the gas mixture, more scrap could be re-melted during the blowing. If pure carbon dioxide was used for the final blow, the iron losses in the slag could be reduced.

In the last decade energetic work has been devoted to the development of the basic Bessemer process. Several modifications to improve the quality of the steel have been tested. One important desideratum was to reduce the nitrogen content of the steel to that of open-hearth steel, and this has been achieved in various ways.

METHODS OF REDUCING NITROGEN

The following methods have been tried to counteract the assimilation of nitrogen during the blows.

Alterations in the Design of the Converter

Shallow baths and a large tuyere area diminish the assimilation of nitrogen by shortening the time taken for it to pass through the bath. According to experiments made by Naeser[1] and Kootz,[2] the assimilation also seems to be counteracted by the presence of free oxygen in the gas phase, and increased blast pressure may have a like effect. Ekman and Hildebrand,[3, 4] and also Kootz,[2] have propounded a theory that during the carbon refining period the reaction of the steel bath with the FeO primarily formed by the air oxidation also produces a considerable secondary oxidation of carbon during the final refining process. This reaction is accompanied by the formation of CO, which at the same time absorbs some nitrogen from the steel. The net change during the refining process is accordingly determined by the difference between the amount of nitrogen assimilated by the direct air oxidation and that given off by the indirect oxidation. Under favourable conditions, even if ordinary air is used in the refining process, the quantity of nitrogen given off may exceed the quantity absorbed, with a consequent reduction of the final content. The design of the converter may also affect the relation of direct to indirect refining and, to that end, Kootz and Gille[5] have used an arrangement of tuyeres concentrated at only a part of the furnace bottom.

Side and Surface Blows

When the blast is introduced either just below the surface from one side, or directed on to the surface from above, the nitrogen in the air will be in contact with the bath for a shorter time, and less will be

Manuscript received 1st May, 1951.

Mr. Kalling, Mr. Johansson, and Mr. Lindskog are members of the research department of Stora Kopparbergs Bergslags Aktiebolag.

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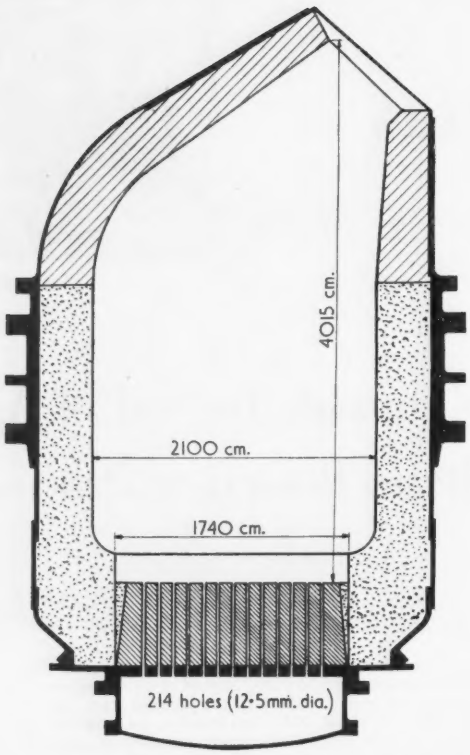

Fig. 1—14-ton basic Bessemer converter at Domnarfvet

absorbed. This usually results in a relatively high iron-oxide content in the slag, which promotes indirect oxidation, and consequent reduction of nitrogen in the fining. This makes possible a very low nitrogen content, as mentioned by Bading,[6] Kootz and Gille,[5] Sims and Toy,[7] and others, and also in the Report on the Bessemer Process.[8] Similar conditions are obtained by side-blowing in ordinary converters, but the nitrogen content will not be reduced as much.

Additions of Ore and Lime

These additions promote indirect fining, and may thus reduce the nitrogen content considerably. The addition of ore during the dephosphorizing period of the basic Bessemer process may also reduce the nitrogen absorption by shortening the blowing time. A combination of side blowing and addition of ore, as practised at the acid Bessemer plant at Fagersta, achieved favourable results.[3] A procedure including the addition of ore, used at Corby, is described by Dickie.[9]

Oxygen-enriched Air

The use of oxygen-enriched air makes it possible to add relatively large quantities of ore or lime during the process, thus reducing the nitrogen content still more. The excess oxygen also produces some direct reduction of the nitrogen content, as less nitrogen will then pass through the bath. Basic Bessemer steel has been produced with oxygen-enriched air at the Maximilianhütte in Bavaria since the early 1930's. Papers on the use of oxygen-enriched air there and elsewhere have been published by Eilender and Roeser,[10] Richthof,[11] Kootz and Oelsen,[12] Coheur and his collaborators,[13, 14] and others.

Pure Oxygen

The use of pure oxygen in the refining process facilitates the production of steel of low nitrogen content, but it cannot be blown from the bottom of a converter, as the high temperature of the reaction would rapidly decrease the life of the bottom. The use of air containing as much as 40% oxygen weakens the bottom when this is of the usual design. If it is desired to use a higher percentage of oxygen, the difficulties are best overcome by blowing the gas on to the surface of the steel from above. Successful experiments in this direction *inter alia* have been made on the initiative of Durrer at Gerlafingen (*see* Hellbrügge[15]) and at Linz, Austria, in a 15-ton converter.

Blowing with Oxygen mixed with some other Non-nitrogenous Gas

If the oxygen is diluted with other gases to reduce the reaction temperature at the tuyere mouths, converters of the ordinary types can also be used. Carbon dioxide and steam have both been used successfully as diluents. The results of comprehensive experiments made in several places in Europe have been published by Daubersy,[16] Kosmider and Hardt,[17] Warnant,[18] and others.

An account of the trials which were made at the Domnarfvet Iron Works, Sweden, using oxygen/carbon dioxide instead of air to reduce the nitrogen content of the ordinary basic Bessemer is given in this paper. These blowings were made between 1947 and 1949 on the initiative of T. Haglund. In 1943 he applied for a patent in respect of this method, which has now been granted in several countries.[19]

EXPERIMENTAL TRIALS

Procedure

All the blows were made in one of the 14-ton

Table I

DATA FROM THE NORMAL BLOWING PRACTICE

		Kg.	
Charge :			
Pig iron		14,000	
Scrap		800	
Lime		1600	
		Min.	
Blowing time :			
Before drop of flame		10	
Up to dephosphorization		2	40
Re-blowing		0	20
	Total	13	0

Analyses :

	Pig Iron	Steel before tapping	Final Slag	
C, %	3·30	0·02	Fe, %	10·0
Si, %	0·30	0·00	Mn, %	2·5
Mn, %	0·70	0·17	CaO, %	50·0
P, %	1·80	0·040	MgO, %	2·5
S, %	0·050	0·030	Al_2O_3, %	1·0
N, %	0·006	0·012	SiO_2 %	5·5
			P_2O_5, %	21·0

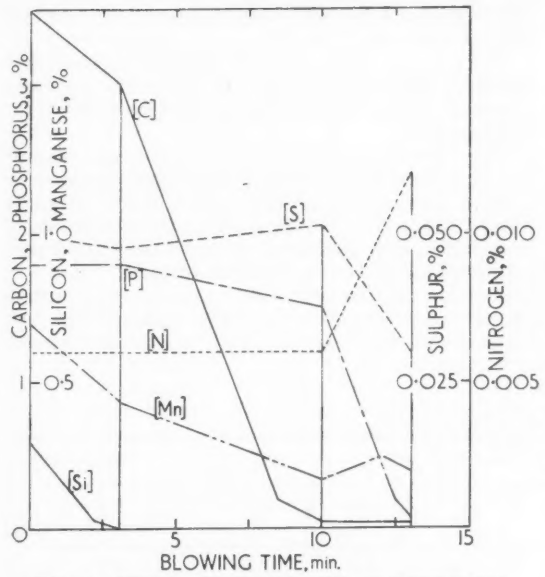

Fig. 2—Current blowing practice at Domnarfvet

converters normally used at that time in the works (*see* Fig. 1).

The blowing process was absolutely normal until just before the 'drop of the flame,' when a mixture of carbon dioxide and oxygen—previously accumulated at a pressure of 285 lb./sq. in. in pressure containers—was substituted for the air. The data from the normal blowings are given in Table I and Fig. 2.

The normal phosphorus content of the steel was 0·070–0·100% in the preliminary tests, and 0·040% after re-blowing. The corresponding steel temperatures, measured by an immersion thermocouple, were about 1625° C. and 1610° C. respectively.

In the final O_2/CO_2 blow every effort was made to adjust the proportion of O_2 to CO_2 in the gas mixture so as to obtain approximately the same relative temperatures as when blowing with atmospheric air. This occurred when about 50% of the gas was oxygen and the balance carbon dioxide. Slightly more oxygen was put in for most of the charges, because when a double-slag practice was used greater heat was required. In the twelve charges the gas contained from 50 to 58% of oxygen. Six blowings have been excluded from the account as unsatisfactory (mostly because there was not sufficient oxygen in the gas).

The more important data are collected in Tables II and III.

Observations on the Trials

The flame was very bright in all the final blowings with oxygen/carbon dioxide, unlike that obtained when ordinary atmospheric air is used, which disappears completely when dropping. This flame was produced by the combustion of the high carbon monoxide content of the converter gases resulting from a partial reduction of the carbon dioxide in the blast to carbon monoxide. The iron fumes, which were forming throughout the blowing, increased towards the end.

The following remarks amplify the tabulated data.

Blowing Time—This was appreciably shortened by the final O_2/CO_2 blowing.

	Time		Analysis at End of Period	
	min.	sec.	C, %	P, %
Average preliminary blowing with air	9	40	0·2	1·4
Average blowing with gas	1	35	0·03	0·033
Total	11	15		

The gas consumption averaged 636 cu. ft. (18 m.³)* of O_2 and 530 cu. ft. (15 m.³) of CO_2 per ton of pig iron.

Nitrogen Content—Changes in nitrogen content during the preliminary and final blows of the different charges are shown in Fig. 3. The amount of nitrogen was not reduced by the final blows although in most of these the gas mixture contained very little nitrogen. Assuming that the solubility of nitrogen in the steel was 0·040% at a nitrogen pressure of 1 atmosphere, it should be possible to reduce the nitrogen content of the steel to about 0·004% if the gas passing through the bath contains only 1·0% of nitrogen. It was

* Values are given at N.T.P.

Table II

DATA FROM INVESTIGATION HEATS

Heat No. :	6	7	9	10	11	12	13	14	15	16	17	18
Charge : Pig iron, kg.	13500	13400	14100	13700	13700	13500	14000	14000	12800	13300	14000	13700
Scrap, kg.	..	400	600	500	500	500	500	500	500	500	400	400
Lime, kg.	1530	1700	1530	1530	1615	1445	1445	1530	1615	1615	1620	1710
Added lime after slag removal and before re-blowing, kg.	..	..	..	..	..	..	500	500	200	200	..	..
Blowing time : Air, min.	12·05	10·56	9·12	7·94	8·38	10·90	10·33	10·24	9·12	9·60	9·70	11·1
Gas, min.	1·56	3·88	1·20	1·56	1·35	1·48	1·34	1·63	1·35	1·53	1·85	2·10
C removed with gas, %	0·02	0·95	0·12	0·15	0·49	0·02	0·08	0·20	0·29	0·09	0·05	0·07
P ,, ,, ,, %	1·27	1·50	1·31	1·64	1·27	1·46	1·29	1·35	1·40	1·63	1·12	1·51
O_2 content of gas, %	50·0	53·7	58·5	56·4	57·3	54·7	57·2	54·3	57·2	55·6	55·5	50·0
Gas consumption, cu. ft.	10300	21400	14800	15000	18200	17500	16100	20100	16600	17200	15000	15900
Steel temperature before removal of slag, ° C.	1618	1638	1638	1700	1666	1650	1650	1660	1634	1616	1656	1642

difficult to determine the amount of nitrogen after passing through the bath, but probably it was so high that no appreciable reduction could normally be expected during the blow.

With the exception of heat 11 with 5·5% of N_2 in the blast, the average nitrogen content during the blow varied as follows :

	%
In pig	0·0050
In steel after air blow	0·0055
In steel before tapping	0·0055
In finished steel	0·0065

The marked increase in nitrogen content during tapping was probably the result of the high nitrogen content (0·95%) of the anthracite used for carbonization in the ladle ; the added manganese alloy contained only 0·015–0·021% of N_2.

The nitrogen content of the finished steel will not diminish appreciably during the final blow and thus depends on that of the bath at the end of the preliminary blow.

The blowing results show that a nitrogen content in the finished steel of about 0·006% may be expected from a preliminary air blow and a relatively short final O_2/CO_2 blow. This is more than is normally found in open-hearth steel, but does not exceed that of unalloyed steel from electric furnaces.

Carbon Content—Blowing with oxygen/carbon dioxide does not reduce the carbon content of the steel as much as blowing with air, owing to the constant

Table III

STEEL AND SLAG ANALYSES

Heat No.	Sample	Pig Iron and Steel						Slag	
		C, %	Si, %	Mn, %	P, %	S, %	N, %	Fe, %	P_2O_5, %
6	Pig iron	3·75	0·21	0·62	1·72	0·051	0·004		
	Before gasblowing	0·04		0·13	1·33	0·047	0·008		
	,, tapping	0·02		0·15	0·060	0·022	0·009	6·9	23·8
	Finished steel	0·05		0·38	0·063	0·030	0·007		
7	Pig iron	3·46	0·27	0·66	1·86	0·033	0·006		
	Before gasblowing	0·97		0·24	1·60	0·037	0·005		
	,, tapping	0·02		0·16	0·098	0·020	0·004	6·5	24·3
	Finished steel	0·04		0·19	0·024*	0·021	0·005		
9	Pig iron	3·15	0·23	0·55	1·61	0·062	0·007		
	Before gasblowing	0·15		0·20	1·34	0·056	0·007		
	,, tapping	0·03		0·12	0·033	0·030	0·007	9·1	21·8
	Finished steel	0·09		0·35	0·070	0·027	0·008		
10	Pig iron	3·05	0·14	0·49	1·68	0·105	0·006		
	Before gasblowing	0·19		0·29	1·68	0·135	0·003		
	,, tapping	0·04		0·07	0·042	0·063	0·004	13·4	22·4
	Finished steel	0·12		0·38	0·041	0·051	0·007		
11	Pig iron	3·39	0·27	0·70	1·55	0·030	0·004		
	Before gasblowing	0·52		0·24	1·31	0·055	0·007		
	,, tapping	0·03		0·11	0·036	0·030	0·005	12·8	19·5
	Finished steel	0·09		0·30	0·051	0·031	0·006		
12	Pig iron	3·34	0·21	0·62	1·72	0·039	0·004		
	Before gasblowing	0·04		0·07	1·49	0·062	0·008		
	,, slag removal	0·03		0·15	0·122		0·008†	7·6	25·1
	,, tapping	0·02		0·03	0·025	0·028	0·009†	23·4‡	13·2
	Finished steel	0·08		0·32	0·039	0·027	0·008		
13	Pig iron	3·21	0·19	0·65	1·68	0·050	0·006		
	Before gasblowing	0·11		0·20	1·32	0·063	0·007		
	,, slag removal	0·04			0·064			11·9	21·1
	,, tapping	0·03		0·04	0·027			27·8	8·2
	Finished steel	0·13		0·57	0·046	0·028	0·006		
14	Pig iron	3·33	0·18	0·81	1·60	0·043	0·005		
	Before gasblowing	0·24		0·39	1·37	0·050	0·006		
	,, slag removal	0·04		0·18	0·077			9·5	22·7
	,, tapping	0·04		0·05	0·021		0·006	20·4	7·1
	Finished steel	0·09		0·47	0·036	0·021	0·007		
15	Pig iron	3·23	0·32	0·81	1·76	0·041	0·005		
	Before gasblowing	0·32		0·23	1·44	0·054	0·006		
	,, slag removal	0·04		0·27	0·094	0·025	0·006	6·7	23·4
	,, tapping	0·03		0·13	0·041	0·024	0·006	14·9	18·1
	Finished steel	0·09		0·47	0·036	0·021	0·007		
16	Pig iron	3·11	0·32	0·82	1·71	0·041	0·004		
	Before gasblowing	0·12		0·64	1·66	0·046	0·003		
	,, slag removal	0·03		0·17	0·066	0·029	0·005	8·1	21·8
	,, tapping	0·03		0·05	0·028	0·026	0·005	18·5	13·2
	Finished steel	0·09		0·36	0·038	0·022	0·007		
17	Pig iron	2·99	0·25	0·45	1·67	0·074	0·004		
	Before gasblowing	0·07		0·10	1·15		0·006		
	,, tapping	0·02		0·06	0·031	0·039	0·007	15·6	19·5
	Finished steel	0·09		0·07	0·031	0·039	0·007		
18	Pig iron	2·78	0·22	0·54	1·84	0·086	0·004		
	Before gasblowing	0·10		0·20	1·55	0·083	0·005		
	,, tapping	0·03		0·12	0·041	0·042	0·005	9·5	23·4
	Finished steel	0·11		0·51	0·059	0·032	0·006		

* Dephosphorization through special treatment
† 5·5% N_2 in gas
‡ Addition of 60 kg. iron ore concentrate before reblowing

supply of carbon dioxide to the gas phase. A reduction to 0·03–0·04%, compared with 0·01–0·02% by ordinary air blows, is usual.

Sulphur Content—As much sulphur was removed as in ordinary air blows. This is shown as follows:

	%
In pig	0·044
In bath at end of air blow	0·055
In steel bath before tapping	0·026

Phosphorus Content—In some of the charges steps were taken to reduce the phosphorus content to a low value. In most cases this was done by the usual method[20] of removing most of the slag just before the end of the blow, adding a fresh quantity of burnt lime, and then repeating the blow for a short while. Owing to unsuitable local conditions, the results were not very satisfactory.

For a given phosphorus content of the steel before any slag was removed, the iron content of the slag in most of the charges increased slightly more than when only air was used in the blows (*see* Fig. 4).

In two of the blows, 9 and 18, in which the blast pressure was kept specially low (about 14 lb./sq. in.) during the final blow in order to reduce the iron content of the slag, very good values were obtained. The phosphorus content is influenced by the temperature, although this is not evident from the experimental results.

Metal Yield—As the gas quantity accumulated in the pressure containers was only sufficient for one blow at a time, no consecutive blows could be made, so that direct determinations of the metal yield were uncertain. There is no need to fear that the yield will be appreciably lowered by a final O_2/CO_2 blow, as this is primarily determined by the iron content of the slag and, in most charges, this was only slightly higher than in normal air-blown charges.

Carbon Dioxide Content and Temperature of Exhaust Gas—The free oxygen contained in the gas passing through the bath during the dephosphorization period is rapidly consumed in oxidizing phosphorus at the beginning and iron towards the end. The carbon dioxide also takes part in the oxidation process and is dissociated into carbon monoxide. If all the reactions were carried to full chemical equilibrium in the converter, the gas phase formed would consist of practically pure carbon monoxide until the end of the dephosphorizing process, but in practice the exhaust gas contains a considerable quantity of carbon dioxide. In one charge the exhaust gas was found to consist of 45% of CO_2 and the balance mainly CO. This analysis agrees well with approximate calculations based on the amount of oxygen given off by the gas passing through the bath.

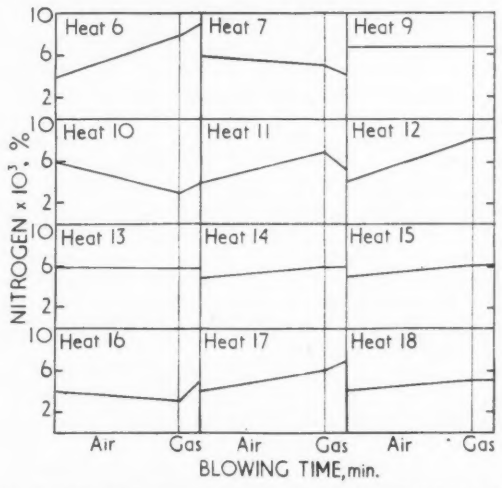

Fig. 3—Nitrogen content of the steel when finishing the blow with oxygen/carbon dioxide

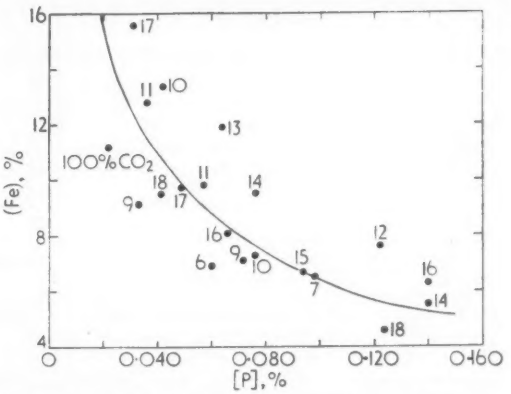

Fig. 4—Relation between iron content of the slag and phosphorus content of the steel. Numbers indicate heat number as reported in Tables II and III. The curve shows iron and phosphorus contents obtained on air-blown heats

The temperature of the exhaust gas has proved considerably higher in blows with O_2/CO_2 than in air blows. In two observations, using Pt/Pt–Rh thermocouples protected by thin quartz tubes and introduced about 4 in. inside the spout, the following values during the same blowing phase were measured:

Gas blow, using 55% of O_2	1420° C.
Air blow	1233° C.

Both these values are, no doubt, too low, but the temperature difference should correspond fairly well with actual conditions. The high temperature of the exhaust gas in gas blows probably results from the primary reactions of the gas with the steel, as the gas used in air blows is considerably diluted by nitrogen and consequently is of larger volume.

Durability of Lining—No numerical values of the durability of the bottom could be obtained, as it was impossible to carry out several consecutive gas blows. Inspection after the blows showed that O_2/CO_2 mixtures produced no greater effects than ordinary air. The iron sculls which generally form round the spout of the converter during air blows were, however, found to melt rapidly during the final blow with O_2/CO_2. This is probably caused partly by the high temperature of the exhaust gas, and its greater emission capacity, and partly by the strongly oxidizing effect on the iron scull of the carbon dioxide in the gas, forming iron oxide of low melting point. There is nothing corresponding to this in air blows, in which the exhaust gas probably consists exclusively of nitrogen.

Table IV

HEAT BALANCE PER 1000 KG. OF FINISHED STEEL

	Kg.cal., × 10^3	
	Air	O_2+CO_2
Heat supplied :		
1024 kg. steel (P = 1·45%) requiring 315 kg. cal./kg. at 1500° C.	322	322
140 kg. undissolved lime + oxides of Si, Mn, P and Fe, requiring 330 kg.cal./kg. at 1500° C.	46	46
10 kg. Fe → FeO, with heat of reaction 1176 kg.cal./kg.	12	12
14 kg. P → P_2O_5, with heat of reaction 5966 kg.cal./kg.	83	83
32 kg. P_2O_5 → 3 CaO.P_2O_5, with heat of reaction 1131 kg.cal./kg.	36	36
Total	499	499
Heat absorbed :		
1000 kg. steel (P = 0·05%), absorbing 338 kg.cal./kg. at 1630° C.	338	338
185 kg. slag, absorbing 510 kg.cal./kg. at 1630° C.	94	94
1942 cu. ft. (55 m.³) N_2, absorbing 13·7 kg.cal./cu. ft. (470 kg.cal./m.³) at 1400° C.	26	...
208 cu. ft. (5·9 m.³) CO_2, absorbing 27·5 kg.cal./cu. ft. (1870 kg.cal./m.³) at 1550° C.	...	8
208 cu. ft. (5·9 m.³) CO, absorbing 15·2 kg.cal./cu. ft. (570 kg.cal./m.³) at 1550° C.		
208 cu. ft. (5·9 m.³) CO_2 → CO, with a heat of dissociation of 86 kg.cal./cu. ft. (3020 kg.cal./m.³)	...	18
Amount absorbed by converter lining + radiation losses (balance)	41	41
Total	499	499

Heat Balance—A comparative heat balance for the dephosphorizing periods in air blows and O_2/CO_2 blows has been determined from the following assumptions :

During the dephosphorizing, 14 kg. of phosphorus are oxidized into P_2O_5, and 10 kg. of iron into FeO. This will reduce the weight of the steel from 1024 to 1000 kg.

The quantity of slag before dephosphorization is estimated at 40 kg. of Si, Mn, P, and Fe oxides, assuming that this slag is not melted. There are also 100 kg. of undissolved lime. The addition of 13 kg. of FeO and 32 kg. of P_2O_5 increases the slag quantity to 185 kg.

For the oxidation of this quantity of P and Fe, 519 cu. ft. (14·7 m.³) of O_2, corresponding to 2472 cu. ft. (70 m.³) of air, will be required. The exhaust gas will then contain 1942 cu. ft. (55 m.³) of N_2. If the blast contains equal parts of CO_2 and O_2, and half the CO_2 content is dissociated, then 417 cu. ft. (11·8 m.³) of O_2 + 417 cu. ft. of CO_2 will be required. The exhaust gas will then contain 208 cu. ft. (5·9 m.³) of CO_2 and 208 cu. ft. of CO.

The temperature of the exhaust gas has been assumed to be 1400° C. in air blows and 1550° C. in gas blows.

The heat balance is given in Table IV.

DISCUSSION OF EXPERIMENTAL RESULTS

The blowing results show that the nitrogen content of the basic Bessemer steel can be reduced to 0·005–0·006% by replacing the air with a mixture of approximately equal parts of oxygen and carbon dioxide during the dephosphorizing period. Neither the dimensions and placing of the tuyeres in the bottom of the converter, nor other features of the design of the converter, need to be changed. There is no need to alter the blowing process, except that the gas valves must be reversed when changing from air to gas mixture.

One advantage of using nitrogen-free gas towards the end of the blow is that a low nitrogen content will be obtained irrespective of the final temperature of the steel. There is accordingly no need to keep the temperature at the cold limit, as in the ordinary basic process ; the temperature of the steel can in each case be adjusted to that required by the method of pouring and the quality of the steel.

A nitrogen content lower than about 0·006% can be effected by using oxygen/carbon dioxide from the beginning of the blow, or by changing to it at a suitable time during the refining stage, but there are other more economic means of doing this.

Although there is no appreciable reduction of the nitrogen content when the change-over to gas blowing is not made until the beginning of the dephosphorizing period, it can be relatively easily reduced to low values during the fining process, partly because the solubility of nitrogen in iron diminishes with increased phosphorus content, and also because indirect refining has a strong nitrogen-eliminating effect which the addition of ore or limestone promotes. The reduction of the temperature consequent on this addition may be compensated by using oxygen-enriched air for the preliminary blowing. It has been found at Domnarfvet that the nitrogen content can without difficulty be reduced by oxygen-enriched air to 0·003–0·004% during the preliminary blowing, and the same content in the finished steel can be attained if O_2/CO_2 is used for the final blow.

A gas mixture of equal parts of O_2 and CO_2 will produce approximately the same temperature conditions as a final blowing with atmospheric air, but there is nothing to prevent an increase of the oxygen content beyond that limit provided that the bath is cooled by an addition of scrap or ore. About 78% of O_2 and 22% of CO_2 has been used, without any apparent extensive injury to the bottom. This reduced the consumption of carbon dioxide and improved the heat economy of the process.

It may be an advantage to keep the free oxygen content of the gas low at the end of the blow to counteract excessive primary oxidation of the iron with consequent high iron losses in the slag. A reduction of the oxygen content of the gas to appreciably less than 50% will result in a final temperature that is too low unless it is kept above normal at the beginning. If the oxygen content is made high in the first stage of the final blowing it can be reduced to a relatively low level, or replaced by pure carbon dioxide, in the final blow. A trial was made in which 3178 cu. ft. (90 m.³) of pure carbon dioxide were used, and showed a further improvement ; the low FeO content is shown in Fig. 3.

The additional cost of using O_2/CO_2 for the final steel refining is not high, being only the cost of the gases used. Carbon dioxide need not cost more than oxygen for equal production volumes, provided that sufficient quantities of combustion gases of about 25% carbon dioxide content, from which it can be extracted, are available at the works. In a large basic

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Bessemer steelworks, where oxygen can be obtained from a plant of say 100 tons/day, the present price of the gas mixture would be approximately 2*s*. per 1000 cu. ft., representing an increase in the cost of $1{\cdot}2 \times 2 = 2{\cdot}4s$. per metric ton of pig iron.

For this extra cost, in addition to the lower nitrogen content, there are other advantages, which include shorter blowing times, reduced air quantity, and the possibility of melting more scrap and ore. A further advantage is that the pouring temperature may be kept higher without any risk of increased absorption of nitrogen, and that it can easily be adjusted to the desired level irrespective of the other aspects of the process. Especially in works where cheap oxygen is, in any case, available, it seems advisable to instal also a small carbon dioxide plant in order to improve still more, if required, the quality of the basic Bessemer steel.

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The Present Metallurgical Bases of Austrian Iron and Steel Production

By Dr. Mont. Ing. Bernhard Matuschka

SYNOPSIS

A description is given of the present distribution and sources of iron and steel production in Austria. It is shown that good conditions exist for the production of a large proportion of high-quality steel.

Plans for the future production of steel in Austria are discussed, and a brief comparison is made between the expected distribution in Austria, once new plant now being constructed at Donawitz and Linz is in operation, and production in Europe as a whole.

Introduction

IRON and steel production in Austria today is entirely based on the country's own ores and fuels.

The basis of production was formerly provided by the ores and rich forests ; today the industry still depends on the same ore deposits in the Styrian and Carinthian Erzberg (' Ore Mountain ') at Eisenerz and Hüttenberg, while the place of charcoal has been taken by Styrian brown coal lignites, like those from Leoben-Seegraben, Köflach near Graz, Fohnsdorf in the upper Muhr valley (Styria), Wolfsegg Traunthal, Upper Austria, and elsewhere.

The only bituminous coal deposit, which is in Grünbach, Lower Austria, is now of little importance to the iron industry. Coking coal and coke must therefore be imported. Coal and ore are situated fairly near to each other, and, as far as mining is concerned, are under the same ownership, that of the Oesterreichisch-Alpine Montangesellschaft, *i.e.*, the Austrian Nationalized Industries.

STYRIAN ORE AND STEEL

Ores

The Styrian Erzberg is a metasomatic deposit, which was formed by the interaction of iron-bearing waters within the deposit and calcareous stone. The conversion of the stone into ore has not progressed everywhere to the same extent, so that only about one-quarter of the mined iron-bearing stone can be regarded as useful ore ; the remaining portion, which is poor in ore, is sent to the waste-heap. The hand-sorted or mechanically jigged ore obtained contains about 30–33% of iron. It is a carbonate type of ore,

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rich in manganese. A further development in the preparation of ore is in progress.

Styrian ore has the following approximate composition :

Substance	Amount Present in Ore, %		
	Lumps	Fines	Calcined
Fe	33	30	45
Mn	2	2	3
P	0·040	0·040	0·045
S	0·08	0·08	0·12
Al_2O_3	2·2	2·5	3·0
CaO	10·0	10·0	12·0
MgO	3·0	3·5	4·5
SiO_2	5·0	6·0	8·0
$CO_2 + H_2O$	32·0	32·0	3·0

In its raw state, it contains about 32% of CO_2, and it must be calcined or sintered before use in the blast-furnace ; this increases the iron content to about 45%. A characteristic of the ore is its high manganese and low phosphorus contents ; the sulphur content is also low, but it increases during calcination. Styrian ore is almost self-fluxing and need not be diluted in the blast-furnace by flux additions ; the burden yield is about 40%, despite the low iron content.

The burden in Styrian blast-furnaces consists almost entirely of Styrian and Carinthian ores. As the calcined ore is comparatively easily reducible, there is a low coke consumption of 800 kg./metric ton (about 1800 lb./long ton), or less, with a blast temperature of 350° C. The calcines sinter together at higher temperatures, which might upset the operation of the blast-furnace ; higher blast temperatures may be sustained, however, if a large proportion of sinter is present in the burden.

Coking Coal

Coking coal has to be imported from the Ruhr or from Poland. Coke is made in the new coke ovens of the Linz Works, and some is also imported from the Ruhr collieries and sometimes from Czechoslovakia.

Pig Iron

The typical Austrian steelmaking pig iron made from Styrian ore has the following average composition :

Substance	Amount Present in Ore, %
C	approx. 4
Mn	,, 2·2–2·7
Si	,, 0·2–0·8
P	,, 0·12
S	,, 0·050–0·070

The pig iron is distinguished by its high carbon content, and more particularly by its high manganese content ; the sulphur and phosphorus contents are low. In composition and properties, it resembles most closely the high-manganese pig irons of Central Sweden. It is an excellent raw material for steelmaking, since its high manganese content is a protection against the action of oxygen during decarburization and refining.

As in Sweden, the Bessemer process was rapidly adopted in Austria because of the availability of manganese-rich pig iron. Formerly, in the puddling and finery processes, and also later when refining in the open-hearth was adopted, the high manganese content in the pig iron proved to be a great advantage. The conditions in Austria have always been favourable for the manufacture of quality steel ; even now, the proportion of high-quality steel produced—about 20% of the total production—is very high, influencing the whole iron and steel production of the country.

Scrap Distribution

The distribution of scrap (which normally amounts to about 50% of the total steel production) between the various steelmaking processes is very different in Austria from that in other European countries.

Owing to the extensive high-quality steel programme, the proportion of electric steel, 15%, is well above the European average of 6%. The electric furnaces take 15% of the available scrap, and the possible scrap addition for making the remaining 85% of the total amount of steel produced in the open-hearth furnaces is reduced to about 40%. The open-hearth furnaces have, therefore, to work with 60% of pig iron and 40% of scrap.

However, 20% of the open-hearth steel is made into quality steel by the 'cold-scrap' process, using only 30% of pig iron ; the remaining 80% of plain open-hearth steel, used for the manufacture of rails, girders, wire, sheets, etc., must be made with a pig-iron proportion that is, of necessity, far above the European average. The two large steelworks at Donawitz and Linz work with only 30% of scrap at most, and with 70% of pig iron, in their open-hearth furnaces. Since the introduction into Austria of the open-hearth furnace, the 'hot-metal' process in fixed furnaces has, therefore, been retained for the most part, in contradistinction to other European countries. As regards cost of raw materials, this is a drawback, but as regards quality it is advantageous.

The manganese content of the charge is 2%. The open-hearth slag contains 16–18% of MnO or 12–14% of manganese. With such a slag, the open-hearth process works very favourably, and needs only 1 kg./ton of manganese for finishing.

Steel Products

The production of ordinary soft steel under such favourable conditions has qualitative advantages : Styrian steel has always had the reputation, particularly among its foreign users, of being extremely ductile and tough, *e.g.*, in wire, rails, and sheets. These properties are also apparent in the harder structural steels and sheets, and in the plain and alloy tool steels. All Austrian steelworks, even those which do not in the main make special steels, retain a quality-steel department within their organization.

Because of the low phosphorus and sulphur contents of the pig iron, these impurities are almost completely absent in the finished steel. The phosphorus content is usually less than 0·020%, and the sulphur content is about 0·030%. The high proportion of manganese-rich pig iron made directly from the ore leads also to high purity in regard to other undesirable elements, such as chromium, nickel, copper, etc. Hence the quality of the scrap is, on the whole, very good, which is especially advantageous for the high-quality production steelworks that use higher scrap charges.

The high manganese content and the purity of the Styrian and Carinthian ores on which the Austrian

iron and steel production is based, have a great influence on the overall quality of the products made from them. A great deal of experience and of detailed knowledge of steelmaking has been gained in the course of years, and metallurgical research has reached a high scientific level.

PLANS FOR FUTURE PRODUCTION

In 1937, Austrian steel production amounted to about 650,000 tons, and pig iron production to 380,000 tons. Even during the war these amounts were substantially increased, and after the war a carefully devised plan was worked out, with the object of directing the new developments and investments to best advantage. This plan provides for a steel production of 1,000,000 tons: the production of rod, sections, and wire is to remain concentrated chiefly at the large Donawitz works of the Oesterreichisch-Alpine Montangesellschaft; the works at Linz, newly built during the war, are to be the centre of sheet production. Special steels are produced mainly in the two large works, Böhler, Kapfenberg, Styria, and Schoeller-Bleckmann, Ternitz, Lower Austria, but, as has been mentioned, quality-steel departments exist also in other works.

Under the European Recovery Plan, the roughing mill of the Donawitz works is being completely replaced by a new American cogging mill, a continuous billet mill, and a new modern section mill for rails and girders, to give a pig-iron production of 450,000 tons/annum and a steel production of 650,000–750,000 tons/annum. The works at Linz remained unfinished during the war. The blast-furnace capacity, with six large blast-furnaces of 650–850 tons daily output, is too large for the scale of the works now planned, and one blast-furnace has already been sold to Sweden, while another two are to be disposed of. The remaining three blast-furnaces will suffice for the annual pig-iron production of 750,000–850,000 tons and steel production of 400,000–450,000 tons now envisaged. Provision was made for the heavy plate mill already installed at Linz to be extended by the addition of a large slabbing mill and a 5-stand continuous wide-strip mill, to provide a modern, semi-continuous wide-strip plant. A cold-rolling mill will follow. To supply these new plants at Donawitz and Linz, an increase of the originally envisaged annual steel output to 1,300,000 tons is necessary and, to reach this capacity, new converter plant is to be erected in these works, for operation with oxygen-enriched blast. The high quality of the steel hitherto attained justifies the hope that the Austrian sheet from the new mill will find a ready export market.

The two large special-steel works, Böhler and Schoeller, have co-ordinated their production programmes so that the Böhler works makes mainly bar steel and forgings, and the Schoeller works mainly bar steel and special steel sheets. Although the production target of 1,000,000 tons has been increased, the basic plan for Austrian steel production remains in force.

Because of the lack of electric power, the large-scale steelworks planning, which had for its aim a far-reaching electrification of pig-iron production, to save up to 450 kg./ton (1010 lb./long ton) of coke, and to conserve a very considerable part of the manganese content of the Austrian iron ores, could not be started. This project also included the proposed building of large electric low-shaft furnaces, by using which the recovery of manganese from the ore was to be raised to 75%. The pig iron was to be blown in the converters so that the high manganese content should pass into a rich slag, suitable for the production of manganese alloys. The separation of the manganese from the pig iron by means of millscale (oxidizing it out of the hot metal) has been suggested. The working of these manganese-rich slags was to cover the entire Austrian demand for manganese alloys, and to make it possible to export, in addition, ferro-manganese to other European countries on a larger scale.

It has already been mentioned that, in the early days, the manganese-rich Styrian pig iron proved specially suitable for blowing in the Bessemer converter. Even though, nowadays, the manganese content is no longer so high, the pig iron is still very suitable for converting. Trials with oxygen-enriched blast, applying a process worked out by Professor Durrer,* gave good metallurgical results, and pilot converter plants and oxygen generators are being erected at Donawitz and Linz. In these modern plants the converter will once more be used for Styrian pig iron. The high manganese content of the pig iron protects the metal from over-oxidation during blowing with oxygen, and ensures the production of nitrogen-free, high-quality steel, similar to open-hearth steel.

If the problem of temperature can be overcome, this process may solve the problem of scrap supply, and bring the production conditions in Austria into line with those elsewhere in Europe. The distribution of steel production in Austria would then be 60% of open-hearth steel, 25% of Bessemer steel, and 15% of electric steel, compared with the European average of 55% of open-hearth steel, 39% of Bessemer steel, and 6% of electric steel.

Whatever form steel production in Austria may take in the future, the good metallurgical conditions will always favour the production of steel of good quality.

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Some Relations of Powder Characteristics to the Elastic Modulus and Shrinkage of Sintered Ferrous Compacts

By G. D. McAdam, B.Sc., Ph.D.

SYNOPSIS

Elastic properties and shrinkage in sintered ferrous alloys, including sintered steels containing manganese and nickel, were studied comprehensively in relation to the properties of the various iron powders, attention being directed mainly to an alloy of the nominal composition: 90% iron—8% copper—2% graphite.

Powders were distinguished in terms of particle dimensions, size distribution, surface shape, density, and moulding characteristics. A detailed description of special apparatus and general test procedure is given, also an account of the method of preparing briquettes under reproducible conditions of mixing, compression, and heat-treatment.

Test results showed that the elasticity E_n expressed as a fraction of Young's modulus E of steel varied with the porosity ϵ in a predictable manner, defined by the expression: $E_n/E = (1 - \epsilon)^{3 \cdot 4}$, applicable to sintered steels and probably more generally to certain cast and heat-treated graphitic materials.

An empirical equation was derived from which it was possible to predetermine the linear contraction of the standard iron–copper–carbon alloys at 1100° C. in terms of the packing, green, and theoretical densities, and the particle size. The approximate elastic moduli of these alloys were deduced from the shape and compression characteristics of powder particles. From these expressions a tentative equation was derived involving a term in particle shape, showing the influence of density measurements, made prior to heat-treatment, on the sintered density.

Introduction

THIS investigation was concerned with the factors governing the elasticity and heat-treatment shrinkage of iron-base powder metals, prepared by cold-pressing and sintering. Experiments were directed to find to what extent limiting values of the variables depended on external influences and on the nature and previous history of constituent powders. Powder characteristics considered to be important were: particle dimensions, shape, size distribution, purity, behaviour in compression, and powder densities.

Schwartz and Junge[1] proved that the elastic modulus of graphitic materials containing temper carbon, or interrupted by spheroidal voids, was proportional to the density. Judd[2] obtained a similar relation for steel-base powder metals, which was confirmed qualitatively for sintered iron by Goetzel,[3] although graphs published in a later report by Squire[4] indicated that a linear variation of elasticity with density was acceptable only for dense metals, and this did not apply to the more porous products. According to Squire, the elastic modulus was not a function of particle size.

Jones[5] noticed that the effect of shrinkage forces in sintering was more marked in unpressed powders, and decided that, apart from the modifying influence of diffusion, the principles governing the sintering of both single elements and mixed powder compacts were probably the same.[6] Hausner[7] concluded generally that the amount of shrinkage was altered by the forming operation and sintering treatment.

Results of Leadbeater, Northcott, and Hargreaves[8] for sintered iron indicated that the change in length, at a constant pressure, is a function of the type of iron. There is general agreement that dimensional changes in sintered iron deposits are significantly affected by particle size, but even in the precise work undertaken by Rostoker,[9] the tacit assumption of a constant particle shape in different size fractions may not be justified. Certainly it is not true for other substances, *e.g.*, sand grains.[10] Wulff[11] reported that the shrinkage of hydrogen-treated iron powders was equally affected by particle shape, purity, and degree of internal strain in the material, whereas the researches of Ellis[12] suggested that size distribution may be as important. Reported evidence of the influence of packing density on shrinkage was inconclusive.[13]

The elastic modulus of powder metals, therefore, appears to be qualitatively related to the sintered density, and independent of particle size. On the other hand, shrinkage (which is modified by subsequent treatment) is believed to be influenced by the physical and chemical state, chemical composition, and degree of subdivision in the powders. The problem is evidently complicated by the numerous variables, and the author knows of no instance in which the properties of a compact were predetermined from the intrinsic behaviour of the powders.

Notation

The following symbols are used:

C = linear percentage contraction of Fe–Cu–C alloys
d_a = arithmetic mean particle size
Δ_A = apparent density of powder mixtures
Δ_G = green, or pressing, density
Δ_P = packing density
Δ_S = sintered density of compacts
Δ_T = true density of powder mixtures

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(a) $R = 0{\cdot}89$ (b) $R = 2{\cdot}61$ (c) $R = 3{\cdot}13$ (d) $R = 3{\cdot}67$

Fig. 1—Microstructures of : (*a*) Carbonyl iron × 1200 ; (*b*) Swedish sponge iron × 40 ; (*c*) reduced oxide iron × 40 ; (*d*) carbon reduced iron × 40

Fig. 2—Microstructure of electrolytic copper (−200 +300 mesh) × 40

Fig. 3—Method of particle size measurement (*d* = statistical diameter) × 80

(a) (b)

Fig. 4—Microstructure of sintered Fe-Cu-C alloy. Etched in mixed nitric and picric acids. (*a*) General micro-structure × 100 ; (*b*) showing hyper-eutectoid structure × 500

Δ_G/Δ_A = compression ratio
Δ_G/Δ_P = compaction ratio
E = Young's modulus of steel
E_n = nominal elasticity of compacts
E_n/E = elasticity ratio
ϵ = fractional porosity
R = coefficient of rugosity (shape factor)
w = mass of powder, g.
S_w = specific surface, sq. cm./g.

EXPERIMENTAL DETAILS

A range of alloys of iron and copper was first examined, mainly because of the availability of the raw materials. Subsequently, tests were made on compacts cold-pressed and sintered under various conditions from iron, copper, and graphite powders. As a result of these tests it was decided to make a detailed examination of an alloy with the nominal composition 90% iron – 8% copper – 2% carbon, prepared under controlled conditions.

In all these experiments, electrolytic copper powder was added in a standard grade, provided by the suppliers in a B.S. (– 200/+ 300) mesh fraction. The powder was cleaned by heating in hydrogen at 300° C. for several hours, which produced negligible adhesion between the particles. High-purity graphite (Acheson Grade 621) of constant particle size was introduced in the proportion of 2% by weight. Iron powders, however, were used 'as received' from the manufacturer, to retain the inherent moulding and sintering characteristics, as it was considered that the shape and ductility of iron particles might be altered by any acceptable purification process.

Twelve iron powders were produced electrolytically under different conditions; nine were of the reduced oxide type, three of these being obtained from Swedish sponge ore; an individual sample of carbonyl iron was received from another source. Table I lists the properties of all these irons, including the properties of synthesized gradings of fine and coarse sponge iron. Extensive tests, however, were made with only four of the iron powders available in bulk (carbon reduced, reduced oxide, Swedish sponge, and carbonyl, respectively Nos. 1, 2, 3, and 4, in Table I).

The shape of individual particles of these irons, and of particles of electrolytic copper, is shown in Figs. 1 and 2; the measured angularity of surface is specified by the rugosity. The order in irregularity of shape of the iron particles was typical of the mass of the powders.

Table I

PHYSICAL PROPERTIES OF POWDERS

Code No.	Type of Powder	Sieve Grading						Mean Diameter of Sub-Sieve Fraction, microns	Specific Surface, sq. cm./g.	Coefficient of Rugosity, R	Bulk Densities, g./c.c.	
		+ 60	– 60/ + 100	– 100/ + 150	– 150/ + 200	– 200/ + 250	– 250				Apparent	Packing
		Mean Diameter, cm.										
		0·0302	0·0199	0·0125	0·0089	0·0068						
1	Carbon reduced iron	..	16·53	38·46	16·98	11·08	16·95	28·54	374	3·67	2·23	2·75
2	Reduced oxide iron	..	2·82	5·41	14·15	17·20	60·42	29·52	599	3·13	2·44	3·07
3	Coarse sponge iron	0·02	0·28	24·80	16·40	21·57	36·93	30·87	354	2·45	2·80	3·60
3a	Mixtures of coarse and fine sponge iron	0·02	0·20	19·50	14·15	16·73	49·40	30·87	414	2·51	2·92	3·74
3b		0·05	0·25	13·90	12·40	10·50	62·90	30·87	492	2·65	2·95	3·88
3c		0·06	0·24	9·62	6·28	8·30	75·50	30·87	542	2·62	2·93	3·85
3d		0·08	0·27	4·44	3·58	4·43	87·20	30·87	597	2·64	2·94	3·83
3e	Fine sponge iron	0·14	0·33	0·40	0·29	5·00	93·84	30·87	668	2·80	2·84	3·67
4	Carbonyl iron	..	..	..	..	..	100·00	4·51	1493	0·89	3·07	4·00
5	Sponge iron	..	1·79	2·37	3·84	11·06	80·94	13·73	3021	6·48	1·07	1·64
6	Reduced oxide iron	..	0·10	14·05	32·14	6·98	46·73	25·53	570	3·10	2·33	2·86
7	" " "	..	0·92	0·02	0·33	0·40	98·33	5·44	3745	2·72	1·23	2·11
8	" " "	..	0·24	9·32	35·33	10·55	44·56	33·01	458	3·04	2·54	3·12
9	" " "	..	0·32	0·23	35·27	32·78	31·40	21·64	985	5·55	1·24	2·11
10	Electrolytic iron	..	2·04	1·76	11·82	5·05	79·33	27·25	525	2·20	2·84	3·56
11	" "	..	5·20	6·86	21·85	5·84	60·25	26·73	480	2·33	2·91	3·78
12	" "	..	17·60	22·02	22·44	11·94	26·00	38·77	239	2·30	3·07	3·87
13	" "	..	0·48	2·02	8·53	69·81	19·16	4·22	1336	3·08	2·16	2·99
14	" "	..	0·43	9·38	18·30	7·19	64·70	40·03	527	3·47	2·50	3·03
15	" "	..	0·09	0·46	14·41	7·39	77·65	33·83	455	2·32	2·66	3·32
16	" "	0·02	0·02	0·07	0·04	0·17	99·68	26·08	1435	4·92	2·19	2·94
17	" "	30·06	61·24	8·51	0·18	0·01	..	..	60	..	3·79	4·47
18	" "	0·17	0·90	32·59	26·55	19·39	20·40	34·63	176	1·61	3·37	4·02
19	" "	0·08	1·58	33·71	19·84	17·91	26·88	34·63	204	1·74	3·12	3·86
20	" "	0·46	0·49	0·97	2·37	19·06	76·65	34·63	396	2·05	3·08	3·79
21	" "	0·57	0·56	0·82	0·82	5·46	91·77	34·63	557	2·72	3·02	3·69
30	– 200/+ 300 mesh electrolytic copper	0	0·03	0·15	0·45	23·99	75·38	46·92	284	..	..	..
31	10μ Acheson graphite 621	..	..	..	..	..	100·00	9·68	34,528	..	..	..

XUM

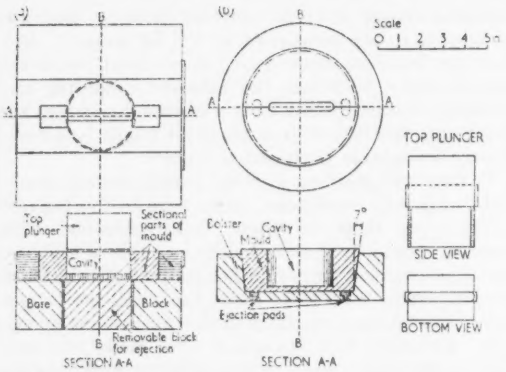

Fig. 5—Diagram of dies used in forming compacts

Powder Properties

Size Distribution—Coarse particles were separated from the powder by means of standard sieves, with average linear openings of 251, 152, 104, 74, and 62 microns, and the sub-sieve material was sized microscopically. There is no general agreement about the most suitable conditions for screening with sieves,[14–16] but consistent results were obtained on 100-g. samples agitated for 45 min. on an automatic sieve shaker. The quantity of powder on each sieve, and the residue, were weighed and the amounts were calculated as a percentage of the original sample. Figure 3 illustrates the method used for determining the particle size in a representative sample of the fines, based on a single microscopic measurement of the particle extremities along a fixed direction. The statistical diameter assigned to a particle was obtained on the assumption that a sufficient number of particles was present in a random sampling to ensure measurements with equal frequency in all directions.

Average Particle Size—The average particle size of the coarse material was taken as the arithmetic mean between the aperture of the sieve which passed the fraction and that which retained it; the size of the fines was considered to be the arithmetic mean diameter derived from the measured sample frequency distribution.

Particle Shape—A factor representing particle shape was obtained by the method of Robertson and Emödi,[17] who related the measured surface of irregular particles to the hypothetical surface of a similarly graded collection of smooth spheres. They defined the degree of divergence from sphericity as 'Coefficient of Rugosity,' which can be expressed by :

$$R = \frac{S_w \Delta_T}{6\Sigma\left(\frac{w_n}{d_n}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where :

w_n = proportion of mass in nth sieve fraction and in sub-sieve range
d_n = average diameter of particles in mass w_n.

Surface—The actual particle surface was determined with an air-permeability apparatus described in detail by Lea and Nurse.[18] A weighed amount of powder was compressed to a bed of fixed depth in a cylindrical cell. Dry air was passed through the bed at a measured streamline rate proportional to the height of a column of liquid in a flow manometer. The pressure drop across a packing was recorded by the difference in liquid level in a second manometer. Values of specific surface were then obtained from the expression :

$$S_w = \frac{\alpha}{wL}\left[AL - \frac{w}{\Delta_T}\right]^{\frac{3}{2}}\left[\frac{h_2}{h_1}\right]^{\frac{1}{2}}, \quad \ldots\ldots\ldots\ldots (2)$$

using a mean value of h_2/h_1 obtained from at least three determinations on the same sample, where :

α = constant (including flow meter constant) = 5933·1 c.g.s. units
A = cross-sectional area of bed, sq. cm.
L = depth of bed, cm.
h_2 = hydraulic gradient, c.g.s. units
h_1 = pressure difference across flow meter, c.g.s. units.

Leadbeater, Northcott, and Hargreaves[8] obtained values of specific surface that were consistently higher when using a deep burette than when using the standard permeability cell. Moreover, they stated that only an arbitrary value of S_w at a fixed height of bed can be obtained for micro-porous metallic powders. In the present work, initial tests showed that the specific surface of a carbon-reduced iron was not altered within experimental error by considerable changes in the depth of bed, values of 369 ± 18 sq. cm./g. and 386 ± 10 sq. cm./g. being obtained for packings of 3 and 15 cm. respectively. Test conditions were subsequently standardized, and the surface figures then obtained were reproducible to within 5% for the entire range of particle sizes.

Density—The true particle density Δ_T was calculated from the specific volumes of separate component powders, assumed to be theoretically pure. Although this is a very close approximation, values of Δ_T for powders with appreciable oxide contents are high.

The apparent density of a mixture was obtained as follows : 100-g. samples of powder were allowed to fall into a standard 50-ml. measuring cylinder from a conical hopper, placed immediately above the container. Gentle tapping was used to break up agglomerates and to disturb bridge and arch formations, care being taken not to transmit vibrations to the mass of powder already collected. Readings of the average undisturbed volume occupied by the fixed weight of powder were taken, from which the apparent density Δ_A was calculated.

The sample collected in the graduated measure was then used for determination of packing, or tap, density Δ_P. The cylinder was dropped vertically under a manually applied load of about 1 lb. on to a rubber stop, from a mean height of 1 in., and was raised and lowered at an average rate of 280 vibrations/min. The powder was thereby gradually shaken to a constant level, optimum consistency being reached in 2–8 min. Densities were computed from the minimum volume occupied by the weighed amount of powder. Figures for packing density were reproducible with considerably less error than figures obtained from equivalent apparent density determinations.

Preparation of Compacts

Mixing of Powders—Powders were weighed to an accuracy of 0·01 g., and were tumbled for 6 hr.

in a horizontal ball mill supplied with six ½-in. dia. steel balls for each 100 g. of sample. The mill was rotated with a slightly eccentric motion at 100 r.p.m., corresponding to peripheral speeds of 0·75 ft./sec. and 1·75 ft./sec. in containers for 100-g. and 1000-g. samples, respectively. After milling for 20 hr., the specific surface of a brittle carbon-reduced iron was increased (from 353 ± 18 sq. cm./g.) by only 16 sq. cm./g., which was within the experimental error of surface measurement.

Pressing—Shallow rectangular compacts, 3 in. long, were formed in the square die shown in Fig. 5*a*, and compacts were prepared in a circular die (Fig. 5*b*), which had parallel faces in the pressing direction. The sides of the latter compacts were curved at the ends, but were parallel for a distance of 2⅝ in.

A weighed amount (30 g.) of mixture was run into a die cavity (*see* Fig. 5), or alternatively a fixed volume (10–12 c.c.) of packed powders was introduced. The bed of mixture was probed with a non-magnetic spatula, which disturbed loose packing arrangements and assisted the compacting of the particles. The surface of the bed was then carefully levelled. The top plunger was inserted, and the die assembly was arranged between the parallel compression plates of a single-acting hydraulic press, of 200-ton capacity ; smaller presses with maximum capacities of 50 and 80 tons were also used. The movable punch was depressed at a rate of 1 in./min., up to the peak load, which was maintained for 30 sec. Pressure was then released and the compacts were ejected, in one instance through the base and in the other by punching out and separating the halves of the split mould.

Density gradients in moulding were minimized by restricting the thickness of the pressings.

Sintering—Compacts were sintered in cylinder hydrogen, supplied at a rate of 8–10 litres/hr., in a Nichrome-wound furnace of the continuous-tube type. The specimens were preheated for 1 hr. up to 1100° C., and were soaked for 1 hr. at this temperature, after which they were furnace cooled. The standard sintering cycle is reproduced in Fig. 6. Temperature readings, measured with a rare-metal couple and deflection meter, were accurate to 5° C., and fluctuations rarely exceeded 0·5%. The indicator was calibrated with a Cambridge potentiometer, used also to check the output of the thermocouple.

DETERMINATION OF PHYSICAL PROPERTIES OF COMPACTS

Green and Sintered Densities

The green, or pressing, density Δ_G of test pieces was estimated from weight and volume measurements. Specimens were weighed to an accuracy of 0·01 g., and average dimensions were checked by micrometer measurement, giving readings correct to within ± 0·0005 in. Densities of duplicate samples agreed within 1%, and this was believed to be the maximum error in estimation.

The sintered density Δ_S was determined similarly, unless the compacts warped during heat-treatment, in which case a water-displacement method was used as follows : Samples were weighed in air, were then immersed in a 5% solution of paraffin wax in xylol,

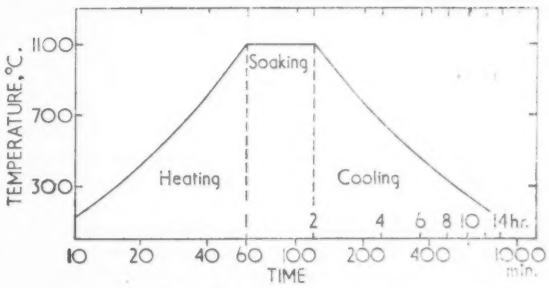

Fig. 6—Sintering cycle in continuous tube furnace

and were reweighed after drying. The thin wax film prevented liquid infiltration into the pores when the sample was afterwards weighed in distilled water at 16–20° C. Figures were corrected for the weight of wax, and for the mass of the wire used to suspend the samples from a balance arm ; the results agreed closely with results of weight/volume determinations on the same samples.

Dimensional Changes

The term heat-treatment shrinkage, or contraction, is restricted to linear changes, which are likely to be greater in magnitude, though not necessarily in proportion, than other dimensional changes. Most of the information needed for the computation of linear shrinkage was obtained incidentally when determining densities from weight/volume measurements.

Elastic Modulus

The nominal elastic modulus of sintered compacts was determined from static bending tests. The test piece, in the form of a shallow beam 0·2 in. thick, was simply supported on oiled knife edges 2 in. apart, and was deflected by a concentrated load at the centre. Loads were adjusted to produce the same order of deflection in every test, and were correct to 0·25%. The deflections, measured with a centrally placed Mercer gauge, could be interpolated to an accuracy of ± 0·00005 in.

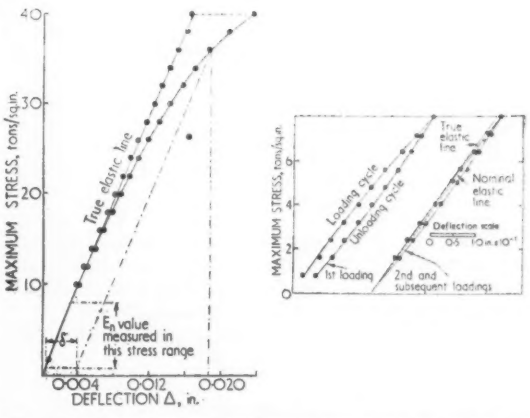

Fig. 7—Typical stress–deflection curve for an Fe–Cu–C compact formed at 50 tons/sq. in., sintered 1 hr. at 1100° C., and furnace cooled (δ = permanent set)

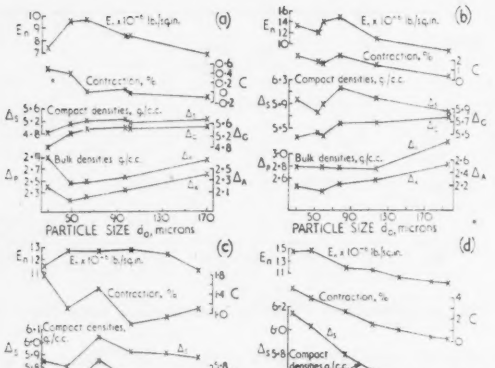

Fig. 8—Physical properties of 90%Fe – 8%Cu – 2%C sintered compacts, as a function of particle size: (*a*) Carbon-reduced iron (No. 1); (*b*) reduced-oxide iron (No. 2); (*c*) Swedish sponge iron (No. 3); (*d*) mixed irons (No. 1 with Nos. 7 and 8)

Permanent set accompanied even small deformations of powder metals, but the load was nearly proportional to the deflection over the small range of loads from 0 to 100 lb. (*see* Fig. 7). The method of deriving the nominal modulus of elasticity from these data is illustrated by the curves inset in Fig. 7; upward and downward traces in the first loading cycle do not coincide, although subsequent cycles over the same stress range were completed without further permanent set. The small initial curvature produced by the first loading was ignored in calculations, which were based on the slope of a line joining the narrow closed hysteresis loop, in the manner adopted by Schwartz and Junge[1] for cast irons.

The relation derived by Timoshenko,[19] between elastic modulus and bending of a beam of rectangular cross-section, can be rewritten in the following form :

$$E_n = \frac{\left(\frac{l}{t}\right)^3}{4w} \cdot \frac{P}{\delta}\left[1 + 3{\cdot}9\left(\frac{t}{l}\right)^2\right] \quad \ldots\ldots\ldots\ldots (3)$$

where :

l = span = 2 in.
t = thickness of beam, in.
w = width of beam, in.
δ = deflection, in.
P = applied load, lb.

The multiplying factor in square brackets represents the additional contribution of shearing force to the deflection produced by bending, and is appreciable for a deep beam stressed over a short length.

The experimental error was computed from the expression :

$$\frac{\Delta E_n}{E_n} = \frac{3}{l}\cdot\Delta l + \frac{1}{w}\cdot\Delta w + \frac{1}{\delta}\cdot\Delta\delta + \frac{1}{P}\cdot\Delta P + \left[\frac{3 + 3{\cdot}9t^2}{t(1 + 3{\cdot}9t^2)}\right]\Delta t \ldots (4)$$

The maximum error was 2·5% for Poisson's ratio = 0·3, differing only slightly if a value of 0·2 was assumed.

In this treatment, the weight of the beam was neglected. Errors caused by the obliquity of the central knife edge, and resulting from variations in cross-section, from lateral buckling, and from axial frictional forces, were all shown to be negligible. Errors produced by the penetration of the supports into a specimen, and by neglecting the displacement of the neutral axis, were examined and were proved to be unimportant. Duplicate tests agreed generally within 2%, showing that the effect of structural irregularities was small. For a mild-steel specimen, the value of $E \times 10^{-6}$ thus obtained was 28·7 lb./sq. in., which was in good agreement with the value (28·4) obtained when the specimen was bent as a 12–21-in. span cantilever, and the value (28·7) obtained by vibrating a horizontal cantilever.

It therefore seems probable that the true modulus E does not differ by more than 2·5% from any of the figures reported for nominal elasticity E_n.

EXPERIMENTS WITH 90%Fe – 8%Cu – 2%C ALLOYS

Determination of Influence of Particle Size on Shrinkage and Modulus

Tests were made with various iron powders, in an attempt to establish the limits of variation in properties of the standard alloy. Compacts were formed at 22·5 tons/sq. in., under the controlled conditions of processing outlined on p. 349, and were then sintered at 1100° C., followed by slow cooling. Properties of the powders are plotted against particle size in Fig. 8.

Carbon-Reduced Iron and Reduced-Oxide Iron—Bulk amounts of irons Nos. 1 and 2 were screened in the manner described on p. 348. The residues on each

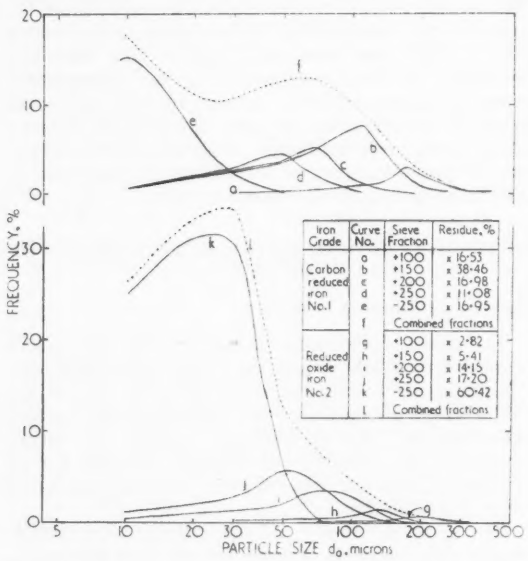
FREQUENCY, %
PARTICLE SIZE d_0, microns
Iron Grade | Curve No. | Sieve Fraction | Residue, %
Carbon reduced iron No. 1 | a | +100 | x 16·53
| b | +150 | x 38·46
| c | +200 | x 16·98
| d | +250 | x 11·08
| e | −250 | x 16·95
| f | Combined fractions |
Reduced oxide iron No. 2 | g | +100 | x 2·82
| h | +150 | x 5·41
| i | +200 | x 14·15
| j | +250 | x 17·20
| k | −250 | x 60·42
| l | Combined fractions |

Fig. 9—Weighted distribution of sieve fractions combined to give size frequencies of graded iron mixtures

sieve, and the amount passing the finest mesh, were weighed and collected separately into five fractions (*see* Table I). Each fraction was sized by the microscopic method, and the classification of the unscreened material was computed from the weighted frequency distribution of sizes in the component fractions.

Distribution curves (Fig. 9) were approximately log-normal, the combined distributions for both irons being represented by broken lines in the graphs. The curve for the carbon-reduced iron differed from that for reduced-oxide iron in that, on the whole, there were more fine particles below a certain sieve size than in the next size interval, a form of distribution sometimes found in a ground material.[20] In this case, the fines were probably increased by small pieces rubbed off larger particles, as the relative blackness of the powder was a sign of impurity that might be associated with brittleness.

Mixtures were prepared to the fixed specification 90%Fe – 8%Cu – 2%C, containing iron powder from each sieve fraction, from the residues, and from the unscreened irons. Powder density and surface area measurements were made before pressing. After sintering, suitable test pieces were machined from the compacts, for measurement of physical properties; results are given in Figs. 8*a* and *b*, and in Table II.

Swedish Sponge Iron—Two bulk supplies of Swedish sponge iron, from the same source, were available for test; one supply was fine powder with an average particle dimension of about 35 microns, and the other was a coarse grade produced in the same process, with a particle size of about 70 microns. Six Fe–Cu–C alloys were prepared from these powders, in the following proportions:

Code No.*	3	3*a*	3*b*	3*c*	3*d*	3*e*
Coarse Grade, %	100	80	60	40	20	0
Fine Grade, %	0	20	40	60	80	100

* *See* Table II.

Results are given in Fig. 8*c*.

Table II

PHYSICAL PROPERTIES OF POWDER MIXTURES AND COMPACTS

Nominal analysis: 90%Fe – 8%Cu – 2%C; moulding pressure = 22·5 tons/sq. in.; sintering temperature = 1100° C.

Code No.	Type of Iron	Arithmetic Mean Particle Size, d_a, microns	Specific Surface, sq. cm./g.	Densities, g./c.c.				Linear Contraction, %	'Hydrogen Loss,' %	Elastic Modulus, lb./sq. in. $\times 10^{-6}$
				Apparent	Packing	Green	Sintered			
1	Carbon reduced	101·4	484	2·30	2·69	5·46	5·29	−0·12	3·1	8·3
1*a*	Sieve fractions of carbon-reduced iron	169·3	232	2·40	2·85	5·50	5·42	−0·09	2·9	7·0
1*b*		97·1	313	2·15	2·57	5·52	5·44	0·05	2·9	8·4
1*c*		63·3	418	2·02	2·48	5·48	5·40	0	2·9	9·6
1*d*		48·6	575	1·95	2·47	5·27	5·31	0·40	3·6	9·5
1*e*		29·3	1351	2·21	2·90	4·85	4·83	0·50	5·8	7·4
2	Reduced oxide	53·3	705	2·34	2·88	5·56	5·74	1·2	1·0	12·0
2*a*	Sieve fractions of reduced-oxide iron	195·1	..	2·52	3·18	5·76	5·74	0·4	2·4	8·0
2*b*		117·2	..	2·28	2·77	5·71	5·98	1·6	2·1	10·7
2*c*		77·9	464	2·23	2·77	5·72	6·15	2·7	1·8	15·0
2*d*		59·3	583	2·16	2·79	5·52	5·87	1·8	2·3	13·8
2*e*		30·2	720	2·23	2·82	5·50	5·98	2·8	1·6	13·7
3	Coarse sponge	69·1	409	2·78	3·64	5·62	5·88	1·1	1·2	11·1
3*a*	Mixtures of fine and coarse Swedish sponge	61·8	448	2·88	3·73	5·66	5·90	0·9	1·4	12·4
3*b*		54·2	514	2·96	3·85	5·68	5·93	0·8	1·4	12·8
3*c*		46·7	544	2·89	3·75	5·84	6·07	1·5	1·8	12·7
3*d*		39·8	701	2·78	3·63	5·60	5·80	1·1	1·5	12·7
3*e*	Fine sponge	35·2	749	2·84	3·69	5·60	5·84	1·8	1·6	11·4
4	Carbonyl	8·4	1856	2·82	3·97	5·05	6·55	8·6	1·3	18·2
5	Sponge	29·7	3163	1·22	1·72	5·07	5·61	3·6	2·7	13·1
6	Reduced oxide	60·6	632	2·34	3·05	5·80	5·83	0·4	0·7	11·4
7	,, ,,	11·3	4239	1·23	1·90	4·92	5·88	6·8	4·5	14·9
8	,, ,,	63·1	535	2·53	3·22	5·96	6·09	0·7	0·6	13·9
9	,,	58·8	1078	2·10	2·67	5·50	5·93	2·9	2·4	12·6
10	Electrolytic	41·9	837	2·75	3·45	5·82	5·82	0·1	0·8	11·9
11	,,	56·7	654	2·75	3·60	5·94	5·88	0·07	0·7	12·2
12	,,	95·1	288	3·15	3·88	5·93	5·92	−0·08	0·8	10·0
13	,,	55·8	2099	2·04	2·90	5·62	5·75	1·2	2·1	11·5
14	,,	58·0	613	2·54	3·10	6·11	6·03	−0·14	1·9	12·4
15	,,	44·7	572	2·60	3·30	6·11	6·10	−0·22	0·5	14·2
16	,,	25·4	1806	2·05	3·08	5·43	6·42	5·5	..	16·7
17	,,	205·3	96	3·84	4·66	..	..	..	..	..
18	,,	81·0	234	3·26	4·03	5·02	5·52	1·3	1·5	6·8
19	,,	80·4	296	3·18	3·99	4·97	5·43	1·4	1·5	7·8
20	,,	45·0	556	2·80	3·70	4·72	5·46	2·8	2·0	8·3
21	,,	40·5	869	2·69	3·63	4·58	5·33	3·1	2·2	8·7
22	Mixtures of irons Nos. 6 and 7 (in 50 : 50 ratio) with proportions of iron No. 1	101·5	494	2·30	2·94	5·45	5·47	0·2	3·1	9·1
23		95·3	670	2·35	3·04	5·45	5·41	0·4	3·8	9·6
24		81·7	1160	2·38	3·28	5·52	5·57	1·0	1·8	10·2
25		71·3	1482	2·42	3·32	5·53	5·64	1·6	3·1	11·5
26		60·6	1746	2·33	3·28	5·45	5·80	2·7	2·9	11·8
27		45·8	2176	2·04	3·08	5·40	6·04	3·9	..	14·7
28		38·1	2197	1·89	2·86	5·37	6·16	4·4	..	14·5
29		36·9	2351	2·32	3·03	5·37	5·22	−0·3	3·2	9·5

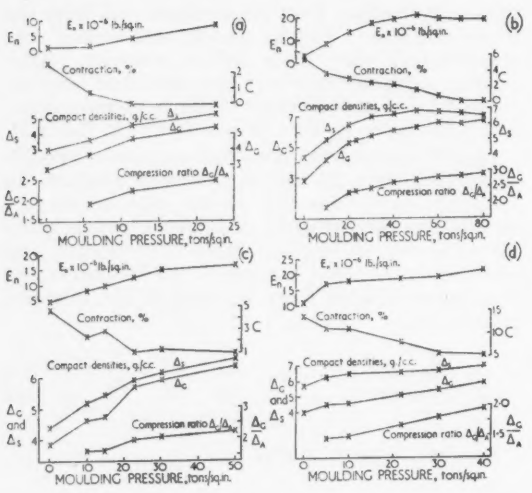

Fig. 10—Effect of moulding pressure on physical properties of 90%Fe – 8%Cu – 2%C compacts: (*a*) Carbon-reduced iron (No. 1); (*b*) reduced-oxide iron (No. 2); (*c*) Swedish sponge iron (No. 3); (*d*) carbonyl iron (No. 4)

Mixed Irons—Alloys were made with coarse iron powder No. 1 and a fine grade composed of equal parts of irons Nos. 6 and 7 (Table II). The coarse and fine grades were blended in different proportions to cover an approximate range of particle size from 30 to 100 microns.

Alloy mixtures prepared with 90% of iron No. 1 flowed readily into the mould, but the rate of flow was inhibited when 10% of the iron was replaced by the finer grade of powder. Successive mixtures containing 30, 45, 60, and 90% of fine grade iron powder (Nos. 24–29, Table II) showed an increasing tendency to agglomerate, making it increasingly difficult to fill the die cavity evenly. Results are given in Fig. 8*d*.

Miscellaneous Iron Powders—Tests were continued with numerous samples of iron powder, available in small quantities. Twelve of the powders were produced electrolytically, and the remaining five by oxide reduction ; the mixtures are given in Table I. Duplicate compacts were formed at 22·5 tons/sq. in., and were sintered at 1100° C., as before. Separate portions of the powders were used to determine the average particle sizes, and these results are given in Table II, code Nos. 5–21.

Determination of Influence of Compaction Pressure

An increase in moulding pressure had the effect of raising the density and elastic modulus of iron–copper alloys made from powders. Similar compacts containing graphite had essentially the same properties when formed at equivalent pressures under identical conditions, and it was therefore logical to expect that the flexural properties of the particular alloy containing 90%Fe – 8%Cu – 2%C could be modified by compaction pressure. Accordingly, tests were made with four different irons for a wide range of pressure ; physical properties of powders and sintered alloys are shown in graphical form in Fig. 10.

Carbon-Reduced Iron—Compacts of standard composition, containing 90% by weight of iron No. 1, were moulded from 12 c.c. of packed powder at 0, 5·6, 11·3, and 22·5 tons/sq. in. The state of zero compaction was established by sintering duplicate samples of packed but unpressed powders, under the same conditions. Test results are given in Fig. 10*a*.

Reduced-Oxide Iron—Compacts containing 90% of iron No. 2 were prepared at 0, 10, 20, 30, 40, 50, 60, 70, and 80 tons/sq. in., alloy additions being made from the same supplies of powder. The compacts were subjected to heat-treatment at 1100° C., as before. Those compacts formed at 60 tons/sq. in. became copper-tinted on all faces, and some copper was expelled from others compacted at higher pressures. The results are given in Fig. 10*b*.

Swedish Sponge Iron—Compacts were made from the synthesized mixtures of irons No. 3 and copper and graphite powders, particle sizes of the iron powder constituent being varied in the manner described on p. 351. Pressings were made at 22·5, 30, and 50 tons/sq. in. ; additional compacts were prepared from the four coarse mixtures at 10 tons/sq. in., and also from the fine powders, although these were formed at 15 tons/sq. in. The effect of sintering unpressed powders was studied in mixtures with 36% and 54% of coarse iron by weight. The variations of E_n value and density with pressure are compared in Fig. 10*c*, and other results are given in Table II.

Carbonyl Iron—Alloy mixtures were prepared to the same specification as before, using carbonyl iron No. 4, which was received in a soft condition, having previously been decarburized by hydrogen treatment at about 400° C., by the manufacturers.

Mixtures were compacted at 5, 10, 22·5, 30, and 40 tons/sq. in., but the compacts were friable even at the highest pressures, and consequently were difficult to handle. To simulate the conditions of treatment at zero pressure, 12-c.c. quantities of mixture were sintered separately in alumina boats, after agitating the powders to a constant level.

Test results are given in Fig. 10*d*.

EXPERIMENTAL RESULTS

Alloy Formation

The mechanism of sintering an alloy of the nominal composition 90%Fe – 8%Cu – 2%C was first investigated with an atmosphere-controlled dilatometer, with which it was possible to make a continuous study of the alterations in length of a compact (formed at 22·5 tons/sq. in.) during heat-treatment in hydrogen. Under the controlled rate of heating, dilatation was halted at 700° C., representing the state when expansion due to heating just balanced the shrinkage in sintering. There was no further abrupt change in length until a marked arrest at the Ac_3 point in iron. Thermal expansion then persisted to a critical point at 1084° C., which evidently corresponded to the liquefaction of copper. Shrinkage continued during the soaking period at 1100° C., after which the furnace was allowed to cool.

During the solidification of copper, shrinkage was

very rapid, but the rate of contraction was restricted for a range of 140° C. by the rejection of cementite below 1000° C. The iron–copper eutectoid was marked by a small inflection at 830° C., indicating a certain amount of alloying between iron and copper. The microstructure was revealed by mixed nitric and picric acid etching, by heat-tinting, and by treatment with boiling sodium picrate solution. A typical microstructure of an alloy richer in copper is given in Fig. 4*b*, which shows refined grains of eutectoid pearlite enclosed by a cementite network containing a large proportion of liquated copper. Figure 4*a* shows the size of the cavities in this specimen, not clearly demonstrated at the higher power.

Particle Size Experiments

In considering the results (Fig. 8 and Tables I and II), characteristics of the loose powders were first examined. The specific surface of the powders of each type increased with decreasing particle size, the finest grade of reduced-oxide iron, No. 7, alloyed with copper and graphite powders, having the greatest exposed surface. Curves for apparent density and loading weight, or packing density, showed a remarkable similarity in form within each group, but differed significantly for changes in the type of iron powder. Fluctuations in bulk density did not necessarily correspond to deviations in green density, and it was unusual for the maximum bulk densities to occur at the smallest particle size. Curves for green and sintered densities were similar only for briquettes processed from carbon-reduced irons and sponge irons. The general increase in sintered density with diminishing particle size, evident in the case of the mixed irons, was imputed to the replacement of irregular grains in the mixture by more even ductile particles of another type.

Figures for heat-treatment contraction showed a tendency to increase with decreasing particle size, irrespective of particle shape but dependent on the type of iron in the mixture. Increase in elasticity values was associated with similar increases in sintered density, with a general reduction in particle size; but, even in fractions of the same iron powder, the finest did not necessarily give the best results, and it was therefore inferred that the modulus was not directly a function of particle size. The influence of packing on mechanical properties was obscure, because the closest arrangements of particles did not always give the most consolidated material after pressing.

Pressure Experiments

Figure 10 shows that, up to 50 tons/sq. in., the qualitative effect of increasing the moulding pressure was the same in all cases, and resulted in denser products which had superior elastic properties, with less shrinkage in heat-treatment (although the numerical values of elasticity and shrinkage, at comparable pressures, evidently depended on the type of iron in the mixtures). Contraction was greatest in the carbonyl grade mixture, and least in the carbon-reduced iron mixture, but otherwise the shrinkage did not follow the sequence of irregularity in particle shape. It was characteristic of all the iron-base

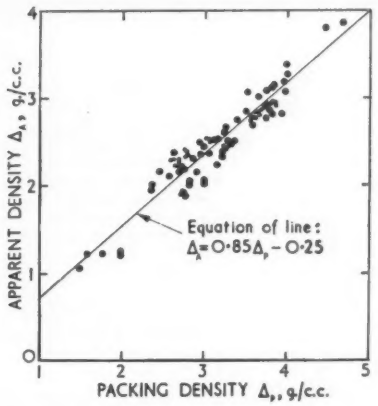

Fig. 11—Regression of apparent density on packing density. (Correlation coefficient $r = 0{\cdot}95$; standard error of estimate $= 0{\cdot}11$)

mixtures that fluctuations in the green density were reproduced, approximately, after heat-treatment. Moreover, the curve for elastic modulus followed, roughly, the form of curves for sintered density, even at pressures exceeding 50 tons/sq. in. A definite discontinuity in the curve for percentage contraction of the reduced-oxide mixture, at 50 tons/sq. in., corresponded to maximum values of elastic modulus and sintered density. The inferior properties of compacts formed at higher pressures were attributed to the expansion of totally enclosed gases during heating, which produced sufficient pressure in opposition to the sintering shrinkage forces to disrupt the walls of the compacts.

Another important feature of these graphs was the considerable influence of moulding pressure on the modulus of elasticity, compared with the relative insensitiveness of this property to large changes in the particle size (*cf.* Figs. 8 and 10).

The lowest curves of Figs. 10*a–d* show clearly that the compression ratio Δ_G/Δ_A was a function of the moulding pressure.

DISCUSSION

The results of this investigation show that there was probably a significant relation between bulk densities, and indicate a possible correlation between elastic modulus and density. The general applicability of these relations was tested with data obtained from experiments on other ferrous alloys, and results were compared whenever possible with published data. Also, the experimental results were examined to find how the inherent characteristics of the iron powder constituent influenced the elasticity and linear shrinkage of a specific ferrous alloy, prepared under controlled conditions.

Relation between Apparent and Packing Densities

The trend observed in apparent and packing densities of 90%Fe – 8%Cu – 2%C alloys (Fig. 8) was

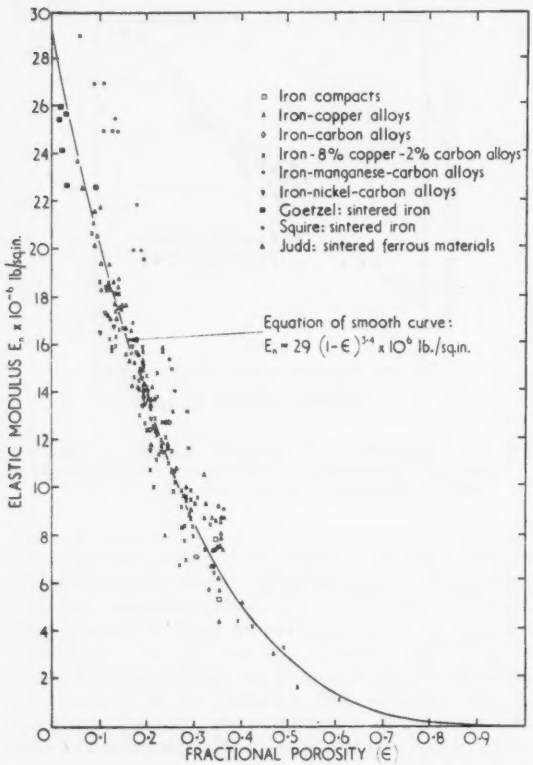

Fig. 12—Relation between elastic modulus and fractional porosity of iron-base alloy compacts

common to steel-base alloys containing manganese and nickel, and to the iron and iron–copper alloys prepared in this research.

The significance of this general agreement between properties was tested by statistical methods. Apparent density was regarded as the dependent variable (because of greater errors in measuring this quantity), and figures for packing density were conventionally plotted as ordinates in Fig. 11. Arithmetic mean values were determined, and the scatter of results about the mean was obtained by calculating the standard deviations. A coefficient of correlation $r = 0{\cdot}95$ was computed from these data. Statistical tables showed that if the value of r exceeded about $0{\cdot}2$ for the 95 observations, allowing for its standard error, there was a significant degree of association between the variables.

Experimental points could then be fairly represented by the regression of apparent density on packing density, for which the equation was :

$$\Delta_A = 0{\cdot}85\Delta_P - 0{\cdot}26 \quad \ldots\ldots(5)$$

Leadbeater, Northcott, and Hargreaves[8] similarly obtained a high degree of correlation between the bulk densities of iron powders, but did not disregard the modifying influence of other factors on the closeness of the correlation.

Relation between Elastic Modulus, Porosity, and Density

In Fig. 12, elasticities of all the iron-base compacts prepared have been plotted against the fractional porosities, for a wide range of compositions and particle sizes. The elasticity of all the alloys was lowered by increasing the porosity. The decrease was progressively more rapid for products with more than 20% of voids, and was independent of the dimensions of the particles. The experimental points tend towards the ordinate axis at a point, corresponding to the true modulus of elasticity of steel, where the porosity is zero. (Laurson and Cox[21] mention a mean value of 29×10^6 lb./sq. in. for Young's modulus of steel, and state that an average of approx. 30×10^6 lb./sq. in. is probably high ; the higher figure is usually accepted for pure iron.)

The smooth curve fitted to the experimental data was based on a linear relation obtained between $\log_{10}E_n$ and $\log_{10}(1-\epsilon)$, and has the equation :

$$E_n = 29(1-\epsilon)^{3\cdot4}, \quad \ldots\ldots(6)$$

omitting units of E_n, 10^6 lb./sq. in., for clarity.

This empirical equation has two limiting values (outside the range of experimental points) pertinent to the present work : elasticities of 29×10^6 lb./sq. in. and 0, and the corresponding porosities 0 and 100%.

The scatter of points was caused partly by experimental errors in elastic modulus and sintered density, and partly by differences in composition of mixtures, and irregularities in the structure of the sintered metal. Other inaccuracies were introduced by using a nominal analysis of the mixtures to calculate the theoretical density, so that no allowance was made for impurities or for losses in heat-treatment.

Equation (6) can be expanded as a polynomial in the form :

$$E_n = (29 - 98{\cdot}6\epsilon + 118{\cdot}32\epsilon^2 - 55{\cdot}216\epsilon^3 + 5{\cdot}5216\epsilon^4 + \ldots\ldots) \ldots(7)$$

Considering the linear terms, applicable to materials with less than 10% of voids, the porosity can be replaced by the sintered and theoretical densities according to the equation :

$$\epsilon = \left[1 - \frac{\Delta_S}{\Delta_T}\right] \quad \ldots\ldots(8)$$

Therefore, equation (7) becomes

$$E_n = 29 - 98{\cdot}6\left[1 - \frac{\Delta_S}{\Delta_T}\right] \quad \ldots\ldots(9)$$

A simplified equation was obtained by substituting for Δ_T a value of 7·7 g./c.c., which represents the weighted mean theoretical density of the alloys investigated. Accordingly :

$$E_n = 12{\cdot}82\Delta_S - 69{\cdot}6 \quad \ldots\ldots(10)$$

This gave a line practically coincident with the regression of elasticity on density for graphitic materials as established by Schwartz and Junge[1] :

$$E_n = 12{\cdot}5436\rho - 66{\cdot}3113.$$

The E_n values according to Judd[2] (Fig. 12) agree well with the present data, provided that the theoretical density of his mixtures can be assumed to average 7·7 g./c.c. rather than 7·5 g./c.c. as reported. Squire's[4] results have been recalculated for theoretically pure materials, and although the elasticity of sintered irons might approach the higher value of 30×10^6

lb./sq. in., the points fall outside the expected range. Goetzel,[3] studying the effect of hot and cold work on the same material, obtained much lower values (Fig. 12).

Substituting ϵ from equation (8) in equation (6) gave:

$$E_n = 29\left(\frac{\Delta_S}{\Delta_T}\right)^{3\cdot4} \quad \text{.....(11)}$$

Then, by expressing the nominal elasticity as a fraction of Young's modulus of steel (29×10^6 lb./sq. in.) a simple dimensionless equation was obtained:

$$\frac{E_n}{E} = \left(\frac{\Delta_S}{\Delta_T}\right)^{3\cdot4} \quad \text{.....(12)}$$

Influence of Powder Properties on Linear Shrinkage

This investigation showed that the shrinkage of 90%Fe – 8%Cu – 2%C alloys, during a standard heat-treatment, was a function of particle size, and was probably independent of particle shape for a particular type of iron, on which the degree of contraction largely depended. Shrinkage was greater in fine than coarse powders, and its effect was reduced by the pressing operation. It was not possible to assess the quantitative effect of pressure directly, because of inconsistencies produced by moving parts of the die, and because of irregularities caused by variations in moulding characteristics of particles of different shape; these irregularities must affect the green density, though in an undetermined, and probably non-uniform, manner. A function was therefore sought as a variable which would be independent of these factors, and which, at the same time, would take into account original differences in packing of the powders in the die.

Figure 10 shows that the compression ratio is a function of the pressure, although reference has been made on p. 348 to the inaccuracy of apparent density determinations. However, the compaction ratio

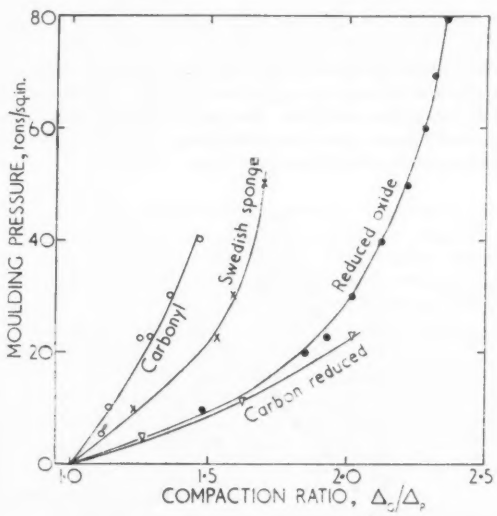

Fig. 13—Dependence of compaction ratio on moulding pressure: 90%Fe – 8%Cu – 2%C mixtures, made with four different types of iron

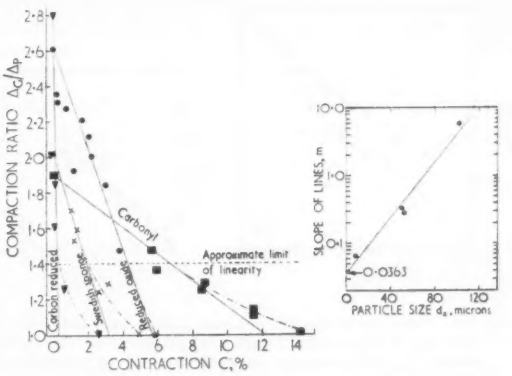

Fig. 14—Heat-treatment shrinkage of 90%Fe – 8%Cu –2%C compacts, as a function of compaction ratio and particle size

(Δ_G/Δ_P) is more accurately determined, and is influenced similarly by moulding pressure. This ratio allows for initial differences in the porosity of a packing, and is independent of frictional forces in the die, whereas the compression ratio, by including the apparent density, assumes the powder initially to be loosely dispersed.

The green density of a compact bears a direct relation to the porosity, but it might also, indirectly, measure particle ductility, because it will be lowered by cleavage of fragments from an impure brittle powder; it may also be a function of particle shape, because it will be altered if rough particles form an internal system of voids by failing to interlock during the pressing operation. DallaValle[22] states that differences in grading of similarly shaped particles, varying only in scale in their dispersion about a mean size, will result in packings of the same consistency: consequently, the form and distribution of particles must influence the packing density, which appears to be virtually constant for each powder mixture examined.

Figure 13 shows that the pressure needed to produce compacts of equivalent density in irons Nos. 1, 2, 3, and 4, increased with irregularity of particle shape, confirming the findings of Leadbeater, Northcott, and Hargreaves.[8]

In Fig. 14, percentage heat-treatment contractions of the same powder mixtures are plotted against corresponding values of compaction ratio. The compaction ratio has a minimum real value of 1·0, representing the state of a packed, but unpressed, powder, sintered (in this case) at 1100° C. under fixed conditions.

It was assumed that a mixture could be compressed to the true particle density ($\Delta_T = 7{\cdot}55$ g./c.c.) to satisfy the highest possible value of the compaction ratio Δ_T/Δ_P, the dimensions remaining unchanged after heat-treatment. There are practical limitations to this assumption, because gases trapped at the higher pressures have been found to resist the sintering forces in these alloys, and may even expand the green compacts. However, the assumption is justified by the trend of experimental points (Fig. 14) towards

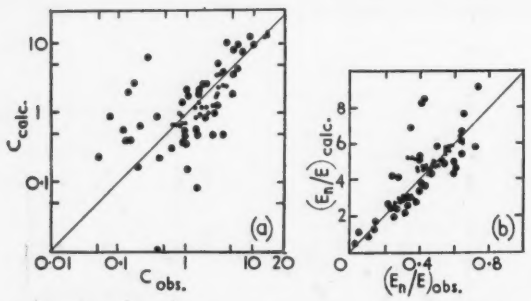

Fig. 15—Comparison between measured and calculated values of heat-treatment shrinkage and elasticity ratio: (*a*) Percentage contraction *C*; (*b*) elasticity ratio E_n/E

the maximum values of compaction ratio, at zero contraction; actual values depend on the original consistency of the packings.

To a first approximation, the variation in contraction may be considered to be linear for high compaction values, but it is undoubtedly non-linear for lower values (the broken lines in Fig. 14). The iron powders were used in an untreated condition, so that looser packings were more readily cleaned of oxide impurities than mixtures formed at higher pressures, where fewer continuous pores might be expected. There was certainly more 'hydrogen loss' on sintering the less consolidated powders, the greater shrinkage being attributed to increased purity of material.

Using this approximation, the curves satisfied an equation:

$$\frac{\Delta_G}{\Delta_P} = mC + \frac{\Delta_T}{\Delta_P} \quad \text{.....(13)}$$

which can be written:

$$-C = \frac{\Delta_T - \Delta_G}{\Delta_P} \times \frac{1}{m} \quad \text{.....(14)}$$

where m = slope of curves.

The negative gradient m of the curves remained the only variable distinguishing one iron mixture from another, and was considered to be related to the average particle dimensions. The carbonyl mixture, with the least slope, had an average mean particle size of 8·4 microns, compared with a value of over 100 microns for the coarser carbon-reduced grade, with the steepest slope. The other mixtures had similar slopes and intermediate particle dimensions.

Examination of the curve of average particle size *versus* gradient suggested that a linear relation might exist between particle size and log m. The figures thus obtained are reproduced inset in Fig. 14. Although the points are not fitted exactly by a simple exponential function, the uncertainty of comparing the diameter of smooth spheres with statistical dimensions of irregular particles, and the limited amount of data, do not justify the use of a more elaborate function. Accordingly, statistical diameters d_a and slopes m were related approximately by the expression:

$$m = -0{\cdot}036e^{0{\cdot}047(d_a)} \quad \text{.....(15)}$$

Substituting for m from equation (14), the calculated shrinkage of copper–steel-type alloys sintered at 1100° C. is given, to a first approximation, by:

$$C_{calc} = \left(\frac{\Delta_T - \Delta_G}{\Delta_P}\right)/0{\cdot}036e^{0{\cdot}047(d_a)} \quad \text{.....(16)}$$

$$i.e.,\ C_{calc} = 27{\cdot}6\left(\frac{\Delta_T - \Delta_G}{\Delta_P}\right)e^{-0{\cdot}047(d_a)}.$$

Jones[13] reported experiments of Bal'shin, who cold-pressed powders to a constant density and found that the tendency to shrink decreased with increasing packing density. In confirmation of this work, it follows from equation (16) that $C \propto 1/\Delta_P$, provided that a constant particle size is also stipulated.

Observed and calculated values of linear contraction for the mixtures given in Table II are plotted in Fig. 15*a*. (The logarithmic scale exaggerates the scatter of small contractions.) Four results could not be reproduced, because compacts actually expanded, whereas the equation predicted a small shrinkage. This was attributed to the resistance of gaseous inclusions to sintering forces, which altered the shrinkage in an indeterminate manner.

Prediction of Elastic Modulus

In Fig. 16, values of the dimensionless group E_n/E were plotted against appropriate values of compaction ratio. To a first approximation, calculated figures fell close to four separate lines (drawn through the arithmetic mean points), which were extrapolated to meet the transverse axis at zero elasticity where the compaction ratio had an imaginary value of 0·8. The position of the point of intersection indicates that a negative pressure is required to prevent particles of a shaken-down powder adhering during heat-treatment, and consequently gives a comparative measurement of the sintering forces in evidence at 1100° C. For a particular mixture, the force resisting the sintering contraction was independent of the type of iron powder, but varied with the nature of the packing.

The straight lines were expressed mathematically by the equation:

$$\frac{E_n}{E} = m\left\{\frac{\Delta_G}{\Delta_P} - 0{\cdot}8\right\} \quad \text{.....(18)}$$

The slope m was steepest for the carbonyl mixture (composed mainly of spherical grains), which meant that irregular particles needed a higher moulding pressure than globular particles, to give identical elastic properties after sintering.

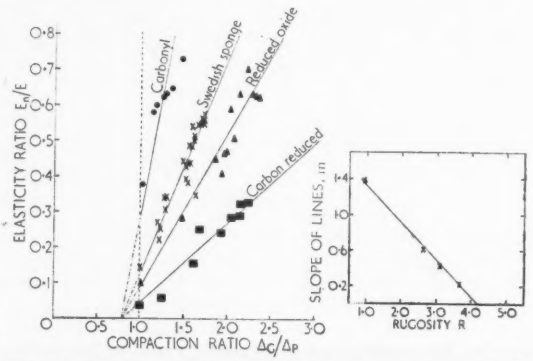

Fig. 16—Relation between dimensionless groups E_n/E and Δ_G/Δ_P, for 90%Fe – 8%Cu – 2%C alloys

XUM

Figures 1*a–d* and 16 showed that increasing angularity in the iron powders was followed by a decrease in the slope of the lines. The purity of the powders, gauged by 'Hydrogen Loss' (Table II) followed the same arrangement, as might be expected, because (other variables remaining constant) the porosity of a random packing of rough fragments increases with the irregularity in shape.

In analysing these results it was argued that adjustments in the grading, or impurities which affected the ductility, would be registered in the compaction ratio. The inclination of the lines was not believed to be governed by particle dimensions, as the finest iron powders of a particular type do not necessarily give the highest E_n values; consequently, the particle shape was believed to be the controlling factor.

The method of Robertson and Emödi[17] made it possible to compare the average surface of the grains with a standard shape, although the relationship between shapes, based on surface roughness, depended on the arbitrary method adopted for classifying particles and evaluating the average diameter from the size frequency data.

The relative angularities of irons and composite mixtures were calculated, but the latter figures were less reliable, because distributions calculated from the gradings of separate components did not allow for the smearing of graphite round the other particles during mixing.

Coefficients of rugosity of the irons were plotted against the slopes m (inset in Fig. 16) and (within experimental error) were found to lie on a straight line, of slope :

$$m = [1{\cdot}73 - 0{\cdot}41R] \quad \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

From equations (18) and (19) the empirical relation :

$$\frac{E_n}{E} = [1{\cdot}73 - 0{\cdot}41R]\left[\frac{\Delta_G}{\Delta_P} - 0{\cdot}8\right] \quad \ldots\ldots\ldots (20)$$

was obtained, from which the elasticity of compacts could be predicted.

Some of the scatter in the main curves, Fig. 16, was attributed to the expansion of trapped gases during heat-treatment. The lower E_n values of these more porous materials would not be allowed for in green density measurements. Other deviations were caused by the inclusion of figures for sieve fractions of slightly different rugosities from that of a classified mixture.

In Fig. 15*b*, calculated elasticities, expressed as a fraction of Young's modulus of steel, are compared with measured values, and show a reasonable degree of correlation. Two estimated figures were negative, owing to the extreme irregularity of particle shape, and two gave values of $E_n/E > 1$; these have not been reproduced in the graph.

Before criticizing these results, the limitation of the fitted equation (20) should be clearly understood. An inaccuracy of 5% in the rugosity of nearly spherical particles altered the calculated values by about 2%, but the same uncertainty in measuring an irregular shape, with a rugosity of 4·0, produced an error of almost 90% in estimated elastic modulus. The empirical nature of the formula must also be stressed, as particles rougher than those of carbon-reduced iron gave negative figures, either because of inaccuracies in measurement or because the rugosity-slope relation (inset, Fig. 16) might be drawn more correctly as a curve.

Density Relationships

By eliminating the ratio E_n/E between equations (12) and (20), the equation :

$$\left(\frac{\Delta_S}{\Delta_T}\right)^{3\cdot4} = \left(\frac{\Delta_G}{\Delta_P} - 0{\cdot}8\right)(1{\cdot}73 - 0{\cdot}41R) \quad \ldots\ldots (21)$$

was formed, showing the influence of sintered density on density measurements made prior to heating. This equation satisfied conditions expressed by Ellis,[12] and Wulff,[11] that the solidity of a finished article depended on the particle shape. The effects of uneven pressure distribution mentioned by other authors were smoothed out by using thin specimens, and by working on average density figures. A term in the equation varied with changes in size distribution, and indirectly measured the deformation resistance of particles The accumulation of errors made it impracticable to deal with equation (21) in more than a qualitative manner.

CONCLUSIONS

(1) The elastic modulus E_n of sintered steels and iron-base alloys is influenced mainly by the voids in the material, and is relatively insensitive to changes in composition. The elasticity ratio E_n/E is related to the porosity ϵ according to the expression $E_n/E = (1 - \epsilon)^{3\cdot4}$, which limits the elasticity of these alloys to a range of 0–29 $\times$ 10^6 lb./sq. in., corresponding to porosities of 100% and 0 respectively.

(2) The porosity of ferrous alloys prepared by the methods of powder metallurgy is determined by the behaviour of constituent powders before and after heat-treatment. For example, the linear shrinkage of certain copper–steel-type alloys, sintered under particular conditions at 1100° C., is roughly proportional to the changes in density brought about by heat-treatment, and (excluding the modifying influence of entrapped gases) is governed by the particle size and density of the powders, according to the empirical equation :

$$C = \left(\frac{\Delta_T - \Delta_G}{\Delta_P}\right)/0{\cdot}036e^{0{\cdot}047(c/a)}.$$

(3) The elastic moduli of specific iron–copper–carbon alloys sintered in hydrogen for a fixed time at one temperature can be predetermined from inherent properties of the powders; the moduli are dependent on particle shape (R) and moulding characteristics, but (within the scope of this investigation) are independent of particle size. This relation may be expressed approximately by the formula :

$$E_n/E = [1{\cdot}73 - 0{\cdot}41R][(\Delta_G/\Delta_P) - 0{\cdot}8].$$

(4) A tentative equation has been derived (equation 21) showing that the sintered density is a function of particle shape, and depends on the behaviour of powders under compression.

(5) Values of packing density, or loading weight, could be replaced in all these equations by the equivalent apparent densities (although with some loss in accuracy) from the expression :

$$\Delta_A = 0{\cdot}85\Delta_P - 0{\cdot}26.$$

(6) Although this research was concerned mainly with the behaviour of a specific ferrous alloy, prepared under fixed conditions, results were believed to have an application to sintered steels generally.

Acknowledgments

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A Method of Examining the Adhesion of Paint to Steel

By S. C. Britton, M.A. and R. M. Angles, L.I.M.

SYNOPSIS

A strip of cellulose adhesive tape, which has been pressed firmly on a painted surface, carries with it, when it is removed by a snatch-pull, areas of paint that have poor adhesion. A reproducible method based on this fact has been developed to compare paints and methods of preparing steel for painting, by revealing the area of paint loosened by corrosion or by controlled physical damage. Manufacturing operations on coated tinplate have been represented by a cupping test, and the damage suffered by paint coatings in service is represented by parallel scratches made mechanically, and by the impact of a falling weight. In corrosion tests, the method is very suitable for use after the provisional standard sea-water spray test.

Results show the improved paint adhesion obtained by phosphating or tin-plating before painting.

Introduction

When painted metal is exposed to corrosion, the paint often loses adhesion over an area extending beyond the visibly corroded zone. Evans[1] showed that the effect of a drop of sodium chloride solution placed on painted steel was consistent with the electrochemical nature of corrosion. At the cathode areas, the development of an alkaline reaction softens some types of paint and generally has a

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deleterious effect on adhesion. Gay[2] demonstrated that the spread of corrosion under a paint film on steel immersed in salt solution, or exposed to its spray, followed the progress of an alkali-producing zone in which the paint was loosened. It seems likely that, for most conditions of exposure, paint loosening is a part of the corrosion process, and may be as important as the more easily detectable rust formation.

The British Standard provisional specification[3] directs that a test panel whose coating has been damaged by scratch and impact be sprayed by artificial sea water : one criterion of failure is a maximum spread of blisters from the damaged areas. The blisters, which are an indication of the paint loosening, are frequently difficult to see and the spread of blisters decreases between the conclusion of the test and the inspection of the test panels. An easy and accurate method of revealing the area of loosened paint was therefore required.

The extent of loosening of paint is also needed in tests, not involving corrosion, where the resistance of a finish to physical damage has to be assessed. The force of adhesion of a paint film to a surface is difficult to measure but its practical effects are rarely dissociated from other properties of the film. It is usually only necessary to know what damage the paint film suffers when it receives the treatment that it is likely to undergo in use. Means of providing such treatment and of revealing the extent of the damage produced have therefore been considered.

PRELIMINARY EXPERIMENTS

It is difficult to develop a standard rubbing or brushing method to remove loosened paint from a corroded surface. The standardization of the tool and of the pressure of application presents many problems, and it is difficult to prevent the wear resistance of the paint becoming an important contributor to the final result. Moreover, any rubbing technique removes the corrosion product with the paint, and useful indications of the causes of the adhesion failure are thereby lost.

Britton[4] has shown that by reinforcing a poorly adherent lacquer film with a strip of adhesive cellulose tape a force can be applied sufficient to remove the lacquer unbroken from the metal. Lacquers applied to tinplate containers have been tested by applying a strip of adhesive tape to a scratch grid on the lacquer and pulling it off. This suggested that adhesive tape might be used to remove paint that had lost all or most of its adhesion.

Steel panels with various surface treatments received a single coat of stoving paint and, after they had been damaged according to the provisions of P.B.S. 1391,[3] they were tested by spraying with artificial sea water. The damage before corrosion included two similar parallel scratches. At the end of the test, after the extent of visible blistering and rust had been recorded, the area surrounding one scratch of each panel was rubbed with fine steel wool until all paint that could be detached, without rubbing through the coating, was removed. The whole length of the other scratch and a $\frac{1}{2}$-in. zone on either side of it were covered with commercial cellulose adhesive tape, pressed in position. A short length of the tape was left free at the edge of the panel, and by pulling this sharply, the tape was jerked from the painted surface. It carried with it areas of paint, which in general corresponded very well with the areas on companion scratches that were bared by abrasion with steel wool. Typical examples are illustrated in Fig. 2. The areas bared by either method tended to exceed slightly the areas of visibly blistered paint. For electrodeposited zinc this excess was large, and the area removed by the adhesive tape considerably exceeded that removed by rubbing. There seemed no doubt, however, of a genuine loss of adhesion ; more prolonged experiments suggested that the adhesive tape revealed developments at an earlier stage. The under-surface of the paint removed showed signs of rust-spread, which had not been visible on the upper surface, and it was clear that the tape method promised a considerable advantage over the rubbing method.

DEVELOPMENT OF THE ADHESIVE-TAPE TEST

The procedure used in preliminary trials had three obvious variables : the method of application, the method of removal, and the nature of the adhesive tape.

Application of the Tape

Provided that the tape was pressed sufficiently firmly on to a painted surface to ensure uniform contact with exclusion of all air bubbles, the application of further pressure had little effect on the load required to remove the tape. Geer and Westcott[5] found that for pressure-sensitive adhesives containing rubber as the basic ingredient, the effect of pressure variation, although readily detectable, was not large. An increase in pressure from 5 lb. to 11·5 lb., on a roller passed over adhesive tape, only increased the load required to remove the tape from 9 oz. to 10 oz.

The paint surface must be free from material such as visible moisture, dried-up salts, dirt, or ' chalked ' paint. The best preparatory procedure is either to wash the test surface with water and dry it in air, or to remove visible moisture with a cloth or blotting paper. When blisters are well developed it is preferable to press blotting paper on to the surface first, to burst them and to remove their fluid content. The drying out of the paint film other than by removing visible moisture can affect the results obtained with some paints (*see* p. 360).

The adhesive tape is applied by pressing down one end, and passing the thumb along the tape, applying a firm pressure, and stroking out any trapped air bubbles to the edge.

Removal of the Tape

The mode of removal of the tape can undoubtedly affect the results. Although a snatch-pull is needed to break the paint film along the edge of the zone of poor adhesion, a wide range of force exists within which satisfactory results are obtained. Nevertheless, to avoid personal errors in hand-removal, a mechanical means of removing the tape has been devised. The method is designed to work with the falling-weight machine described in P.B.S. 1391.[3] A photograph of

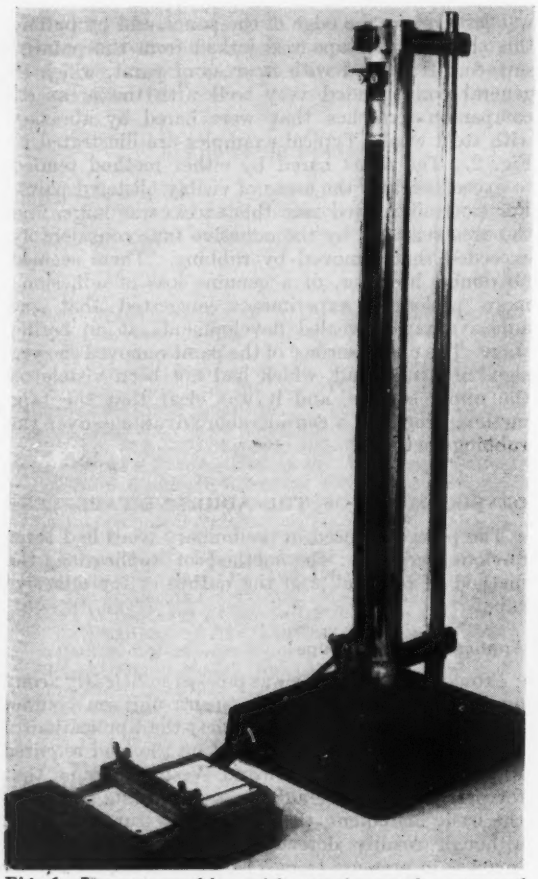

Fig. 1—Impact machine with attachment for removal of adhesive tape from test panel

the machine with the tape-removing device is shown in Fig. 1.

A weight is allowed to fall from the top of a vertical tube on to the end of a metal bar pivoted on a fulcrum fixed to the bottom clamping ring of the tube of the machine. One end of the bar projects into the tube between the vertical division and the other end rests on a block to which the test panel is clamped horizontally. The tape projecting from the end of the panel is fixed to the upper surface of the outer end of the bar. The fall of the weight produces a sufficiently rapid and forceful rise of the other end of the bar to remove the adhesive tape from the panel satisfactorily and reproducibly. The total length of the bar is 10 in. and it is pivoted 2 in. from the inner end.

Another method, which requires no special apparatus, is available, but the removed tape is more liable to be crumpled. The panel with tape in position is supported 18 in. above the bench with test side downward, and the free end of the tape is passed round a light bar and stuck to itself to form a loop supporting the bar. A 2-lb. weight is tied to a clip by a 12-in. piece of string and the clip is fixed on the bar with the weight supported immediately below it. The weight is then allowed to fall freely and pulls off the tape with the requisite jerk.

Properties of the Tape

The tape used must be strong enough to withstand the snatch-pull needed to remove it whole. The force used must be less than that required to pull paint away from a surface to which it adheres, but must be greater than that required to break the paint film across a width equal to that of the tape. These properties are exhibited by cellulose adhesive tape supplied to Ministry of Supply Specification C.S. 2500. To provide the required tensile strength the weight of tape should be not less than 60 g./sq. m. Most of the tape sold for packaging is suitable.

Timing of the Test

The adhesion of some primers can be reduced sufficiently, even before corrosion commences, for the paint film to be detached by the adhesive-tape method by the absorption of water, as was shown in tests on painted glass. Adhesion lost in this way is restored as the paint dries out, but the loosening produced in the corrosion process is a permanent effect.

The adhesive-tape test can therefore be used to assess the liability of paints to suffer adhesion loss in a moist environment : for this purpose the test must be applied immediately after the withdrawal of the painted panel from the moist conditions. To determine the effect of corrosion only, the test should not be made until the paint film has lost its imbibed water.

Although the effects of corrosion on the paint adhesion are permanent, the complete removal by the tape test of areas of paint loosened in laboratory corrosion tests becomes progressively more difficult over a period of weeks, owing to changes in the corrosion product. Therefore, to obtain the true conditions under the paint at the end of the test, the tape application should not be delayed more than 48 hr.

The choice between the immediate application of the adhesive tape at the end of a test and a later application, must depend on the nature of the test being made. In corrosion tests such as that in P.B.S. 1391,[3] where a primer only may be applied, it might be unfair to condemn, for loss of paint adhesion by wetting, the protective system of which the prepared and primed surface forms a part, since the application of finishing coats might prevent a damaging access of water to the primer. It is generally recommended therefore that, except where the effect of soaking is being specially studied, paint should be allowed to lose water either by holding for a few minutes in a current of warm air or by keeping in a desiccator for 2 hr.

Summary of Requirements

The requirements of the method of removing loosened paint may be summarized as follows :

(1) Clear transparent pressure-sensitive adhesive cellulose tape conforming to Ministry of Supply Specification C.S. 2500 is needed. A 1-in. wide tape is generally most useful.

(2) The test surface is rinsed with water to remove loose materials such as dirt, 'chalky' paint, and dried-up salts, and is dried by keeping in a desiccator for 2 hr.

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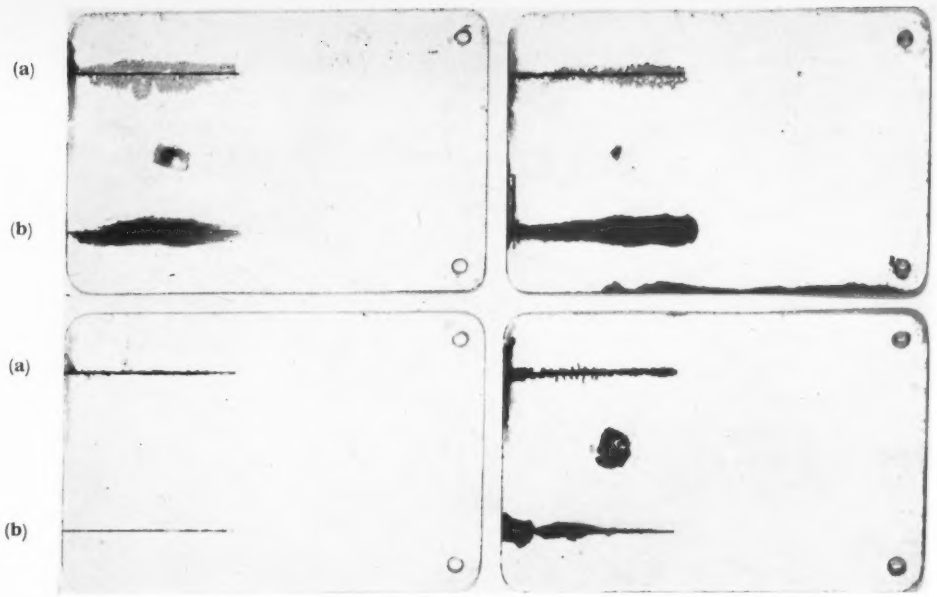


Fig. 2—Painted panels subjected to the corrosion test of P.B.S. 1391,[3] and then deprived of loosened paint : (*a*) By adhesive tape ; (*b*) by rubbing with wire wool

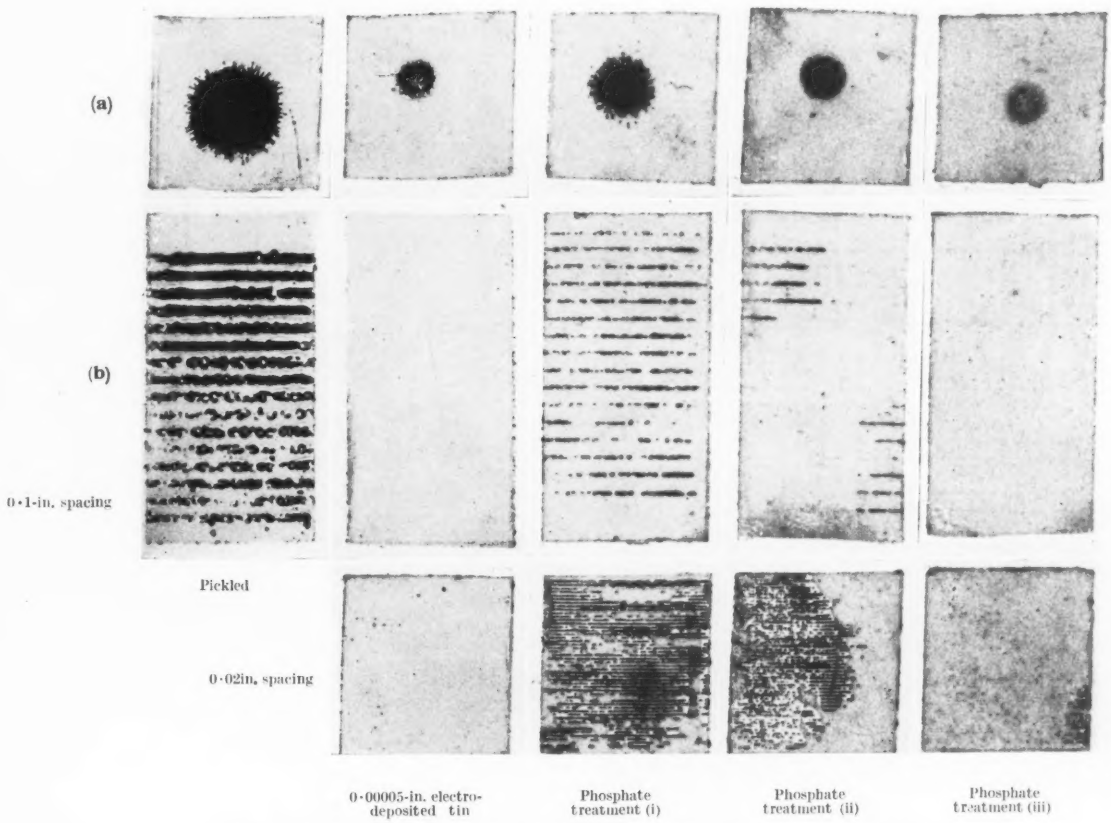
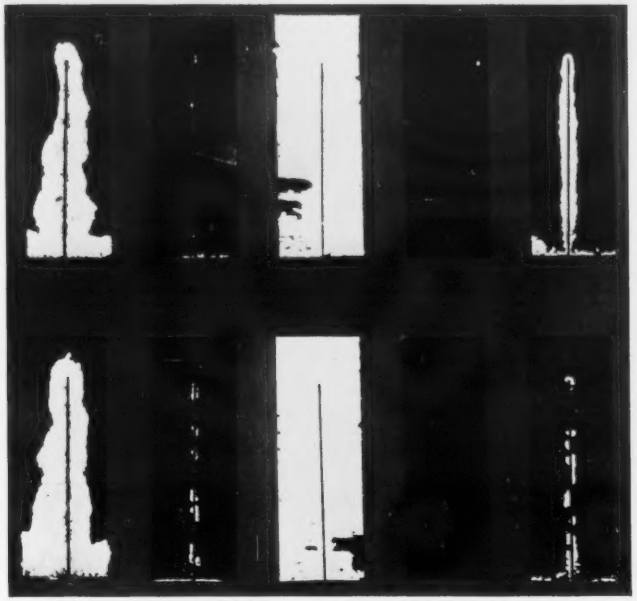
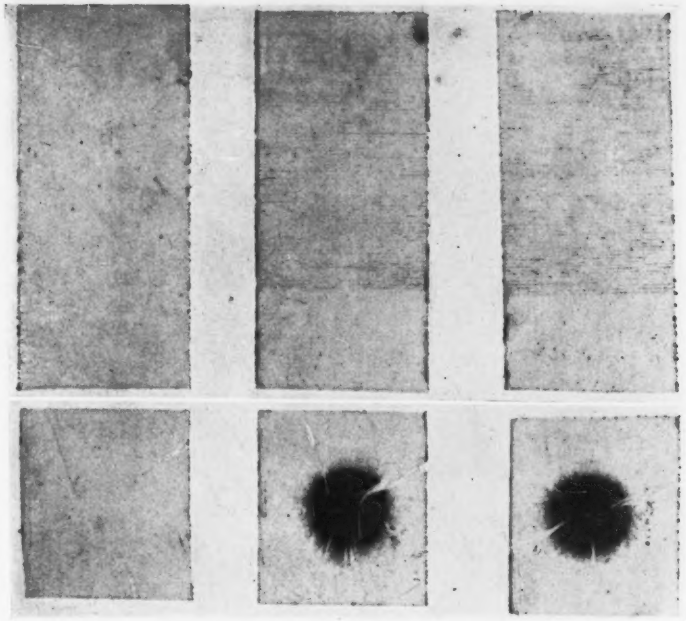


Fig. 3—Typical patterns of paint detached from specimens with various surface treatments : (*a*) After impact damage ; (*b*) after scratching



Bare Steel | 0·00005-in. electrodeposited tin | 0·0035-in. electrodeposited zinc | 0·0005-in. electrodeposited zinc, phosphated | Phosphated Steel

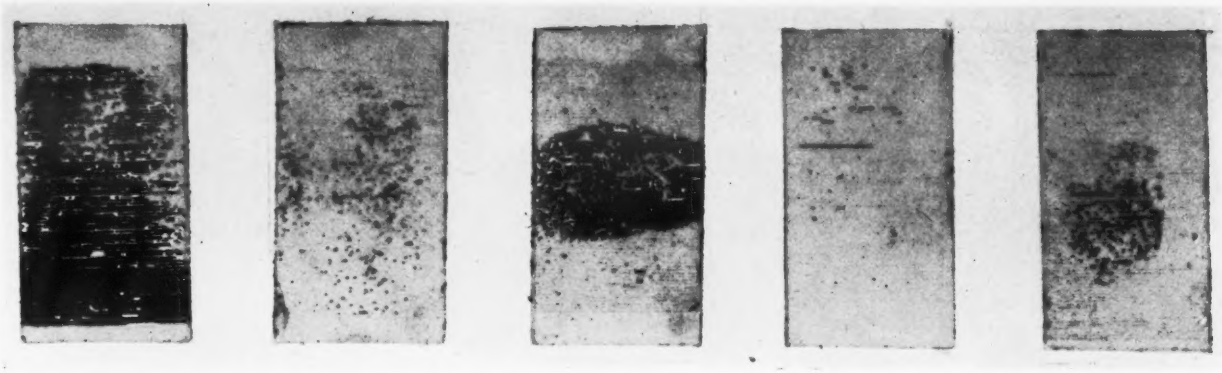
Fig. 4—Adhesive tape strips carrying paint removed from scratches on panels subjected to corrosion after various surface treatments



(a)

(b)

Fig. 5—Adhesive tape strips carrying lacquer from tinplate coated with different 'gold' lacquers after: (*a*) Scratching; (*b*) cupping test



As-received tinplate | Degreased tinplate | Degreased tinplate marked with greasy finger | 0·00005-in. electrodeposited tin on steel | Electrodeposited tin marked with greasy finger

Fig. 6—Typical patterns of paint detached from specimens with various surface treatments

(3) A strip of the tape, large enough to cover the area to be tested, is pressed firmly on the surface, leaving at least 1 in. of tape free.

(4) The tape is snatched quickly off the surface by pulling sharply on the loose end.

RESULTS OF TAPE TEST

The results to be described have been obtained by removal of the tape either by hand or by the aid of the mechanical devices already described. No distinction will be made between them because the authors obtained the same results by either method. The mechanical aids are considered to be essential only when results obtained in different laboratories are to be compared.

The method has been used to study loss of adhesion caused by physical damage and by corrosion. These two effects are considered separately.

Effect of Corrosion

The reproducibility of the test as applied to the corrosion test of P.B.S. 1391[3] was checked by applying each of two synthetic resin stoving paints to 24-S.W.G. mild-steel panels with five different surface treatments. Satisfactory agreement was obtained, within sets of five panels, for each combination of paint and surface treatment.

There were only two scratches where less paint was removed than had appeared to be blistered, and the differences between these amounts were within the errors of blister measurement. For paint applied over untreated electrodeposited zinc, the areas stripped greatly exceeded the areas of visible blistering, but for all other treatments the two sets of observations corresponded. In general, the area of paint removed by the tape was only slightly greater than that seen to be blistered. Adhesive-tape strips carrying paint removed from scratches made on panels with various surface treatments, after 11 days' test, are shown in Fig. 4.

The mean value of the measured lateral spread of paint deterioration from the scratches, for each set of 10 replicates, is shown in Table I.

The extent of blistering was measured when the blisters were most easily visible, *i.e.*, immediately after the conclusion of the corrosion test. By the adhesive-tape method, the extent of the paint loosened can be measured much more easily ; the panels need not be examined immediately after the end of the test ; rusting under the paint, not evident on the upper surface, can be revealed, and a permanent record can be obtained both on the test panel and by preserving the stripped tape. (The tapes carrying detached paint can be mounted on transparent sheet so that a permanent record of both surfaces of the paint is preserved. Cellulose acetate sheet, 0·005 in. thick, has been found very suitable for this purpose.) The method can be as rapid as visual examination since the search for blistering is time-consuming. The tape method is, of course, useful only at the end of a test and visual observations must be used during progress of the test.

Records of the development of rust under paint in many conditions, including laboratory tests in an atmosphere containing 20 p.p.m. of sulphur dioxide, have been obtained. Under these acid conditions, the area of paint loosened corresponds very closely with the corroded area, but detachment of under-rusted paint may reveal corrosion not evident on the upper surface.

The spread of adhesion failure from a scratch, as revealed by the use of the tape test after the corrosion test of P.B.S. 1391,[3] does, for different methods of surface preparation, well represent the comparative spread of corrosion from scratches in natural weathering.

Apart from its use in comparative testing, the tape method has possible applications in research. It is well suited for use in testing the inhibitive character of primers, by studying the effects of drops of salt solution placed on the paint coating with or without a scratch.[6] Smaller effects are revealed than are shown by rubbing away loosened paint and, using the method on a series of drops after different time intervals, a record of the development of the corrosion can be made. The method may perhaps be used to study the mechanism of corrosion spread under paint.

Because of the failure of the adhesive tape to pull off all paint covering hard rust, the method is of greater value in accelerated tests in the laboratory, where a softer rust is usually formed, than in natural weathering tests. Nevertheless some useful indications have been obtained on panels exposed out of doors. Some paint may be detached outside the visibly corroded area ; the amount depends on the paint, the nature of the surface to which it is applied, and on the exposure conditions. As in laboratory tests, the loss of adhesion is more widespread in salt-laden atmospheres. In these atmospheres the corroded areas are surrounded by an area of uncorroded metal from which the paint is readily detached. Each area of paint detachment is associated with a corroded area, suggesting that the spread of rusting is preceded by the loosening of paint on an uncorroded cathodic zone.

In examining material carrying hardened and aged rust, visual inspection of the extent of rust and the application of the adhesive-tape method give a more complete picture of the extent of the corrosion damage than is provided by either alone.

On naturally weathered panels, as in laboratory tests, the tape method has revealed adhesion failures associated with slight under-film corrosion, which could not be detected on the upper paint surface, and it makes readily apparent such failures as may

Fig. 6—Typical patterns of paint detached from specimens with various surface treatments

As-received tinplate
Degreased tinplate
Degreased tinplate marked with greasy finger
0·00005-in. electro-deposited tin on steel
Electrodeposited tin marked with greasy finger

Table I

MEAN VALUE OF TEN OBSERVATIONS OF SPREAD OF DAMAGE TO PAINT

Surface Preparation	Paint 1		Paint 2	
	Visible Blisters, in.	Paint Removed by Tape, in.	Visible Blisters, in.	Paint Removed by Tape, in.
Pickled	0·25	0·31	0·20	0·23
0·00005-in. electro-deposited tin	0·04	0·04	0·07	0·08
0·0005-in. electro-deposited zinc	0·14	0·5	nil	0·5
0·0005-in. electro-deposited zinc, phosphated*	nil	nil	nil	nil
Phosphated*	0·03	0·06	nil	nil

* The process used was an accelerated zinc phosphate type.

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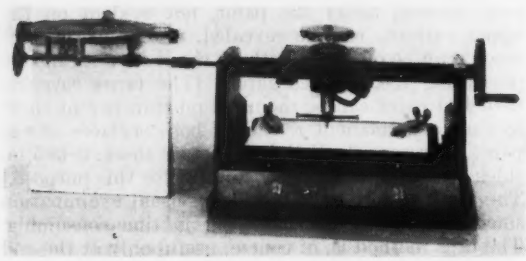

Fig. 7—Machine for production of parallel scratches

occur on inadequately prepared zinc surfaces. Surfaces on which under-rusting at many points may cause adhesion loss, are not always those that show the greatest development of serious rusting on more prolonged exposure, but, in most practical applications, loss of paint adhesion is itself important owing to the risk of further damage by rough treatment.

Effect of Physical Damage Without Corrosion

The methods in use for testing the liability of paint films to suffer damage on physical maltreatment are usually quite effective, but both the infliction of the damage and the interpretation of the result are often peculiar to one operator. The adhesive-tape method of removing loosened paint may therefore provide a means of improving such tests.

Three types of damage met with in practice have been examined—indentation by impact, indentation by press tool, and scratching.

Impact Damage—For the study of impact damage, the falling-weight machine[3] has been used. Adhesive tape is applied to the surface under test and the weight is allowed to fall on the reverse side of the panel. The tape is then removed by a snatch-pull.

Typical patterns of detached paint, shown in Fig. 3*a*, illustrate the use of the method for comparing the effects of the surface preparation of 24-S.W.G. mild steel prior to painting. The impact blow required depends on the material under test ; in Fig. 3*a* a 2-lb. hammer was allowed to fall 9 in. The paint may crack without being appreciably detached from the surface and such cracks are revealed more clearly by the tape test than by brushing or rubbing damaged areas. By mounting the tapes on a suitable background the evidence may be conveniently preserved or photographed.

Scratch-Testing — For scratch-testing, scratches should be made with precise spacing and in a reproducible fashion. It was found advisable to make each cut individually by a mechanical scratch method. The machine used was an adaptation of a sclerometer designed for scratch-hardness testing of metals. Other forms of scratching device could no doubt be adapted to give similar results.

The machine, shown in Fig. 7, has the test panel mounted horizontally on a carriage, which can slide on dovetail grooves. A gramophone needle, acting as a scratching tool, is held vertically in a chuck mounted at the lower end of a vertical cylinder retained in a sleeve bearing. The upper end of the vertical cylinder carries a small platform on which weights can be placed as required. The bearing carrying the scratching tool can be moved, in a direction perpendicular to the direction of travel of the carriage carrying the panel, by rotation of a small hand wheel. The number of rotations of the hand wheel is shown on a revolution counter and, to facilitate exact movements, a contact point is fixed to give a warning light at the end of each half-revolution, *i.e.*, at each 0·01 in. of travel. The scratches are made by lowering the needle point on to the paint surface and moving the panel support on its slide a predetermined distance (usually 1 in.), which is fixed by stops at each end of travel. The needle can then be traversed by the hand wheel to a desired distance and a further scratch made.

When scratches have been ruled to cover the total distance, the panel is lightly brushed with a soft brush to remove loose particles contained within the actual scratches, and a tape strip is applied at right angles to the scratch lines. When it is snatched off, it brings with it paint loosened alongside the scratches. The tape may be mounted on a surface, contrasting in colour with the paint, so that different paints and different surface treatments can be compared.

A close spacing permits the easiest assessment of the result, since the general density of the pattern can then be appreciated without measurement of the width of paint removed, but the spacing must be greater than the width likely to be completely covered by detached paint. For less adherent paints on relatively smooth surfaces, a 0·05-in. spacing is convenient. Where a very slight detachment is obtained a spacing as small as 0·02 in. has been used.

Some patterns obtained with different paints on three surfaces have already been published.[7] Some additional illustrations are shown in Figs. 3*b* and 6. Figure 3*b* illustrates the results obtained for two scratch spacings, one at 0·1 in. and the other at 0·02 in., for a range of surface preparatory treatments under a single coat of cellulose lacquer. This lacquer was readily detached from the unprepared steel surface by scratching alone, making it quite impossible to use close scratch spacing on that surface. Even the pattern with wide spacing is ragged owing to some loss of lacquer before the tape was applied. Figure 6 shows patterns obtained with a scratch spacing of 0·02 in. for a cellulose lacquer applied to a series of tinned surfaces. The effect of grease removal from tinplate and the rather better adhesion obtained on an electrodeposited tin coating (as-plated) as compared with the hot-dipped tin coating can be seen. The areas of adhesion-loss produced by greasy fingerprints are well defined.

The loading on the needle is adjusted so that the scratch penetrates the thickness of the paint, but does not cut deeply into the basis metal. Overloading has little effect on paint applied to bare steel or to steel coated with thin deposits of metal or phosphates, but with soft materials such as aluminium, a too heavy loading causes a slight ridge formation, which interferes with the application of the tape and may cause an unfair disturbance of the paint. It is preferable to use a lower load than is necessary to cut through the paint in one movement of the panel and to make a double movement, once in each direction,

if serious displacement of the metal is threatened by heavier loads. The weight of the needle holder (95 g.) is a sufficient load for thin lacquer coatings on tinplate, but an additional load of up to 200 g. has been found necessary for some paint coatings. The needles used (Columbia Goldtone) normally make several hundred scratches without an appreciable change in the results obtained, but this depends on the material under test and on the loading.

The scratch machine can be employed to cut in two directions, at an angle, to produce a grid similar to that often used in the study of paint coatings, but a more definite result is obtained by a parallel series of scratches followed by the adhesive-tape treatment.

Deformation by Pressing

Some light steel articles are formed from sheet, which has already received an organic coating. Tinplate, for example, may be required to retain a protective or decorative coating while subjected to severe deformation in the production of containers. A cupping test, using the Avery Sheet Metal Testing Machine, gave the required type of deformation. The machine presses a 2-cm. dia. steel ball into the clamped metal sheet to form a cup. Cups were pressed out to a depth of 3 or 5 mm. in all the samples to be compared, and the adhesive-tape technique was then used to remove loosened paint from the convex surface of the cup. It is not possible to spread the tape over the cup without creases, but placing the tape before deformation, as in the impact test, is difficult because it may be cut or become entangled in the clamps.

The adhesive-tape method seems to be particularly useful in this test because it demonstrates loosening of coatings, which could not easily be revealed in any other way. Figure 5 shows the patterns produced in tests on some tinplate lacquers. These tests were in line with the behaviour of the materials in factory pressing operations.

In studying multi-coat paint systems, this test, like the impact test, gives an indication of the liability of different paint coats to separate from each other.

Discussion of Physical Damage Tests

None of the various methods used to damage the paint films before applying the adhesive tape gives an absolute measurement of any property of the paint film at the surface. The physical properties of the paint film itself, as well as its adhesion to the surface are involved. The methods are, however, considered to be of practical value in comparing the probable resistance of protective systems to forms of mechanical damage likely to be encountered in service. The results obtained are affected by the thickness of the paint film and, with some paints and surfaces, by the time elapsing between paint application and test. The application of the coatings and conditions of test must therefore be standardized and a number of replicate tests should be carried out.

The comparative results obtained for the effect of mechanical damage have not diverged from those given by other simple methods, when the tests are conducted by one operator. Results obtained by different operators vary less, and it is far easier to compare the adhesive-tape records than to compare marks in the panel surface, especially when small differences are involved.

CONCLUSIONS

(1) The application and removal by a snatch-pull of pressure-sensitive adhesive cellulose tape has been found useful for removing areas of paint coatings where adhesion has been impaired. This method can be used for testing and in research involving the destruction of paint adhesion by corrosion and by physical damage. It is superior to the removal of loosened paint by rubbing because it is more easily reproduced and the evidence of changes on the underside of the paint can be preserved.

(2) The test is particularly suitable for the examination of test panels after the sea-water spray corrosion test to P.B.S. 1391,[3] and for this purpose a simple standard mechanical means of removing the tape has been devised.

(3) The removal of loosened paint after scratching or indentation by impact is considered to give a useful guide to behaviour in typical rough treatment encountered in service. The application of the tape method after a cupping test provides an indication of the ability of tinplate to hold an organic coating when it is deformed in manufacturing operations. For scratch testing, a mechanically produced series of parallel cuts through the paint, followed by use of the tape test is recommended.

(4) The test is comparative and tapes carrying the detached paint can be mounted on a suitable surface and readily compared and stored for future reference, or photographed.

(5) The results obtained in corrosion tests and in physical damage tests have been consistent with general experience in showing the limitation on the spread of deterioration achieved by suitable methods of surface preparation before painting, such as coating with electrodeposited tin or treating with phosphate solutions.

Acknowledgments

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The 2000-Year Tradition of the Austrian Iron and Steel Industry

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SYNOPSIS

The growth of the Austrian iron industry, which is based on two main sources of ore in Carinthia and Styria, is traced from early Roman times to the present day, particularly in regard to the development of the modern coke blast-furnace from early reduction furnaces. Mention is made of the finery fires of the Middle Ages, which were gradually superseded by the puddling process. The effect of the invention of the Bessemer process was comparatively small, and this process declined and disappeared when the open-hearth process was invented. The electric furnace process is also of great importance.

The main Austrian steelworks are given, and the development of steel fabrication and other associated industries, with the economic development of the Austrian iron and steel industry, is discussed. The growth of the Austrian tradition of quality and craftsmanship is mentioned, and examples are given of some of the works of art produced in the last two centuries.

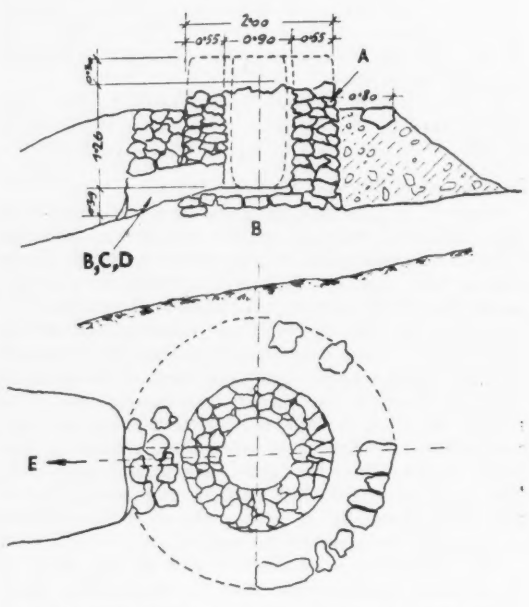
EARLY IRON PRODUCTION IN AUSTRIA

THE period from 900 to 500 B.C. is known as the 'Hallstatt Age,' since at that time, near a place called Hallstatt in the Salzkammergat in Upper Austria, salt was mined from the same deposits as are worked today. Iron weapons and tools of a high standard have been found in graves near Hallstatt, and the iron slags that have been found there suggest that these weapons were made in the vicinity.

Apart from these suggestions of the existence of a very early iron industry in Austria, the mining and smelting of iron ores are known to have been practised long before the birth of Christ; there is no doubt that the Alpine Celtic tribe of the 'Norics,' who lived in what is now Carinthia and Styria, had a well-developed iron-smelting industry before the Roman occupation in 16 B.C., and that the Romans traded in the famous 'Noric iron.' The main sources of ore were at first in the region of the Hüttenberg ore mountain in northern Carinthia. The incorporation of the country into the Roman Empire under Augustus provided a further impulse to the iron industry, owing to the great demand of the Romans for steel tools of all kinds. Figure 1* shows a low-shaft furnace of that period, for the reduction of iron ores, which was excavated in excellent condition at Lölling, near Hüttenberg.

The Romans probably found the Styrian ore mountain while they were pushing the frontiers of the empire up to the Danube (although the local inhabitants almost certainly knew of it long before), and they quickly realized the importance of this source of iron for their arms- and tool-forges, so near to the fortified camps of the Danube frontier. Roman coins found in an old mine-shaft of the Styrian ore mountain and in the town of Eisenerz indicate that both mining and smelting were certainly being carried out there in the time of the Emperor Constantine, although operations probably started centuries earlier. A Roman road exists about three feet below the level of the present 'iron road,' which runs from Leoben *via* the Prebichl pass, skirting the Styrian ore mountain and thence through the valley of the river Enns to the Danube. It served, in Roman times as in subsequent centuries, for the transport of iron and of the materials necessary for its production.

In addition to the Styrian and Hüttenberg ore mountains, there are many smaller iron-ore deposits that, from the earliest times, were the basis of important local iron industries. Economic pressure during the last 100 years has forced the closing of these small mines, and the importance of the Styrian and Hütten-



A Uppermost layers with some lime-mortar
B Slag
C Burnt loam
D Charcoal
E Slag-notch

Fig. 1—Roman shaft furnace at Lölling, excavated by W. Schuster

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* W. Schmid, "Norisches Eisens," *Beiträge zur Geschichte des Oesterreichischen Eisenwesens*, 1932, vol. I, No. 2, Fig. 13.

Fig. 2—Iron-ore deposits in Austria

berg ore mountains has therefore become more marked. The uninterrupted 2000-year association of iron-smelting with these two sources of ore is probably unique, and the high quality of Noric steel (praised by Plinius the Elder,* who died in 79 A.D.) has remained, up to the present day, a carefully preserved tradition.

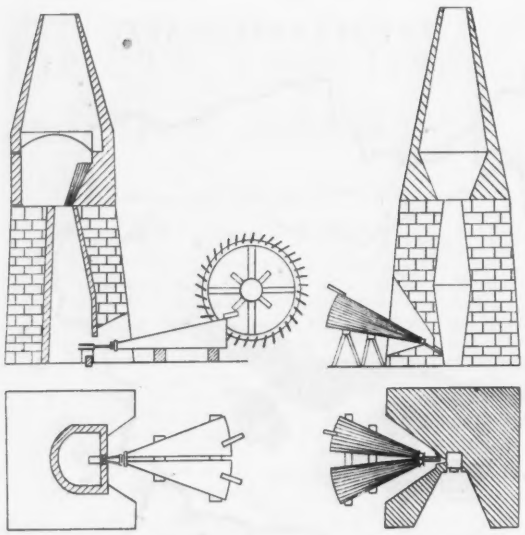
NATURAL RESOURCES

The location of the main Austrain ore deposits is shown in Fig. 2. The shaded areas indicate the zones that are geologically connected ; an appreciable number of isolated deposits also exist. The northern and most important group lies on the border between the northern Kalkalpen and the Uralpen (Zentralalpen), *i.e.*, on a large tectonic line of disturbance. In the eastern section, iron ore is preponderant, the largest concentration being in the Styrian ore mountain. In the western section, non-ferrous metals exist, although in much smaller quantities.

The evolution of the iron deposits is of a metasomatic nature, *i.e.*, the original lime was changed by iron-bearing vapours or solutions (which could rise easily along the area of tectonic disturbance) almost completely into iron carbonate (siderite). In and around the Styrian ore mountains, there are about 100 million tons of iron in the form of siderite with an iron content of at least 33% ; there are, also, considerable quantities of lean ore. The siderite contains about 2% of manganese, has a very low phosphorus content, and is virtually free from sulphur; furthermore, it is nearly self-fluxing. The Styrian ore mountain, which is the main source of raw material for the Austrian iron and steel industry, is about 5000 ft. high ; mining is nowadays mainly open-cast, there being 60 benches reaching a height of about 2400 ft. (*see* Fig. 3).

Fig. 3—The Styrian ore mountain (Oesterreichisch-Alpine Montangesellschaft)

* Plinius, *Natural History*, vol. XXXIV, Chapter 41; *see* W. Schmid, *Beiträge zur Geschichte des Oesterreichischen Eisenwesens*, 1932, vol. I, No. 2, p.171, ref. 4.



(*a*) A Styrian *Stückofen* (*b*) A Carinthian *Flossofen*

Fig. 4—Profiles of reduction furnaces in the second half of the 18th century

Of the other iron-ore deposits of the northern group, only that at Radmer in Styria, and a small one at Werfen, near Salzburg, are now mined.

The second group of deposits lies in the central Alps, the most important being the ore mountain of Hüttenberg, in Carinthia. It is unfortunate that these ore reserves are no longer large, for the Hüttenberg siderite has a higher manganese content than the Styrian ores. The smaller deposits of the central Alpine group are no longer worth mining.

The third group of deposits is on the border of the Uralpen towards the southern Kalkalpen; they have never been of great importance, and none of them is worked today. Non-ferrous deposits, particularly of lead, exist in important quantities in these districts.

So long as the smelting of iron was carried out with charcoal, Austria had an ample supply of fuel from the large Alpine forests; but it was necessary to decentralize charcoal burning, and the smaller iron-ore deposits were smelted near the mines. Ample water power was available everywhere for driving the blowers. It is true that the smelting industry based on the Styrian and Hüttenberg ore mountains was already very preponderant in the days of charcoal practice, but to nothing like the extent that it is today.

The development of the coke blast-furnace was a serious blow to the Austrian iron industry, as Austria has no deposits of bituminous coking coal. The change-over to coke smelting was made with hesitation, because of the necessity to preserve the old-established and famous quality of the steel. Not until 1870 was the first coke blast-furnace blown-in, but since then a large-scale iron industry has been built up on the basis of imported coke and coking coal, and the qualms about quality have been overcome by advances in metallurgical practice. The development of electric steel, on a large scale, has played a significant part in the growth of the steel industry, based on Austria's ample supplies of water power.

FROM EARLY REDUCTION FURNACES TO THE MODERN BLAST-FURNACE

From the early shallow pits with low side-walls and primitive bellows, giving very inadequate reduction, there had developed by Roman times a shaft furnace about 3 ft. high with bellows of better construction (*see* Fig. 1). Not until the middle ages were the bellows driven by water power. In addition, the increased blast-pressure made possible the use of a higher shaft and a larger burden, and gave much better reduction of the ore. Such furnaces were called *Stückofen* (bloomery fires) in Austria, and their main product was an agglomerate of low-carbon iron crystals and slag, *i.e.*, wrought iron. With increasing furnace heights and blast pressures, and with the resultant higher temperatures in the reduction zone, a high-carbon liquid iron must have been obtained at an early stage as a reduction product, in addition to the crystalline low-carbon iron. This liquid iron was called *Graglach*, and was at first looked upon as an undesirable and useless by-product; it was soon found, however, that by letting it drip through an air blast on to a charcoal hearth it was possible to convert the liquid iron into forgeable steel. *Graglach* eventually became the sole product of the reduction process, particularly as its economic and technical advantages became known and were developed. Thus the *Stückofen* changed first into the *Flossofen* and eventually developed into the blast-furnace itself.

Fig. 5—Ruins of the *Fuchs-Flossofen* at Hüttenberg-Heft in Carinthia. Ceased operation in 1793

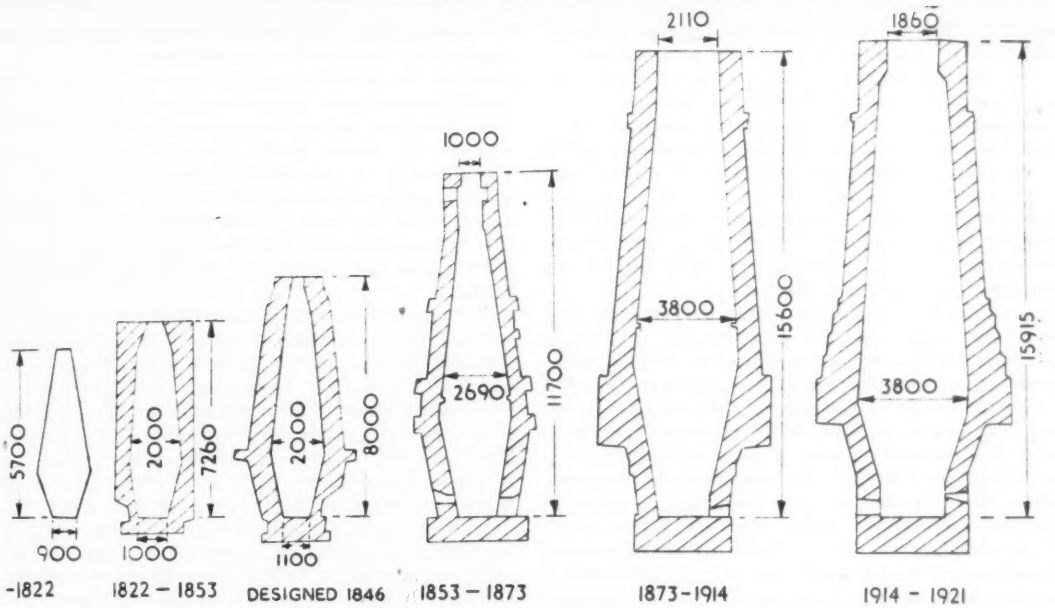


Fig. 6—Development of the profile of the blast-furnace (' wheel-plant ') III at Vordernberg, 1822–1921. (According to W. Schuster)

This transition proceeded very gradually, however, and *Stückofen*, *Flossofen*, and blast-furnaces were all in operation in Austria up to the end of the 18th century. The same furnace was often run, at different times, as a *Stückofen* and as a *Flossofen*, by changing blast and temperature conditions and by altering the shape of the lining. Figure 4*a** is a diagrammatic section of a Styrian *Stückofen* as used at the end of the 18th century; it was finally capable of smelting almost a ton of iron in one run. Figure 4*b*† shows a section of a Carinthian *Flossofen*, and the ruins of such a furnace near Hüttenberg are illustrated in Fig. 5‡.

After the end of the 18th century the blast-furnace superseded all other types, and although many small blast-furnace plants near the various scattered ore deposits received their charcoal from the surrounding forests and their water power from nearby mountain streams, a concentration of blast-furnaces grew up in the immediate vicinity of the Styrian ore mountain, and this often caused difficulties with charcoal supplies. At Eisenerz, at the northern foot of the mountain, there were, originally, 19 shaft furnaces, which eventually developed into three fairly large blast-furnace plants. At Vordernberg, on the south side, there have been 14 blast-furnaces of various sizes. A very early agreement existed between Eisenerz and Vordernberg, whereby the latter mined the upper part of the mountain, from which the ore could be transported horizontally to the Prebichl pass (3950 ft.) and thence down to the furnaces, while Eisenerz mined the lower part of the mountain. The co-existence of the many independent iron plants (or *Radmeister*, *i.e.*, ' wheel-masters,' as they were called after the water-wheel drives for their blowing engines), each having mining rights on a small portion of the mountain, led to much friction, which was overcome only when the individual concerns were later fused into larger combines.

The development of the profile of Vordernberg charcoal blast-furnaces from about 1820 to 1920 is illustrated in Fig. 6. From the first small furnace with thick stone walls, which made about three tons of pig iron per day, a furnace with a capacity of 60 tons of pig iron per day was developed. This large unit required a mixture of 60% hard and 40% soft charcoal, the former being brought from the beech forests of Slavonia (Yugoslavia). The difficulty in obtaining this charcoal after the collapse of the Austro-Hungarian Empire was one reason why the last Vordernberg blast-furnace ceased operation after 1922. The formation of the Oesterreichisch-Alpine Montangesellschaft in 1882, and the amalgamation with it of the major part of the Alpine iron industry, paved the way for the rapid construction of large modern coke blast-furnaces at Donawitz and at Eisenerz, each of which reached a capacity about ten times greater than that of the largest charcoal furnaces hitherto used. This led to the concentration of pig-iron production at Donawitz and Eisenerz, and to the closing down of the small ore mines and blast-furnaces in other parts of the country. In 1938 a step was taken in the other direction, when, by the building of the works at Linz, a second large-scale centre of pig-iron production was created. Although this plant is farther from the native ore supply than that at Donawitz, it has good transport facilities and is thus able to supplement the Styrian ores with foreign

* O. Johannsen, "Geschichte des Eisens," p. 40, Fig. 42. Düsseldorf, 1924 : Verlag Stahleisen m.b.H.

† *Ibid.*, p. 65, Fig. 71.

‡ "Die Oesterreichisch-Alpine Montangesellschaft, 1881–1931," p. 465, Fig. 208. Wien, 1931 : Julius Springer.

imports. The original basis of the old Austrian industry has thus been changed, to some extent.

The present blast-furnaces at Donawitz and Linz are among the most efficient in Europe; coke consumption (to which Austrian blast-furnacemen have always paid great attention because supplies have to be imported) has been reduced to less than 16 cwt. per ton of iron, a figure which compares favourably with the consumption at other plants in Europe. The comparatively cool-blown manganese-rich pig iron is an excellent raw material for the production of high-grade steels.

In addition to the large plants at Donawitz and Linz, one small charcoal blast-furnace is still in operation in the Konkordiahütte at Werfen, near Salzburg, for making high-grade grey cast iron.

The possibility of pig-iron manufacture in electric and oxygen-blown low-shaft furnaces has been actively investigated with a view to reducing the amount of blast-furnace coke that has to be imported. Trials have shown that it is technically possible to operate successfully with Austrian brown coal. At present, however, the available supply of electrical energy is sufficient to make only a limited amount of special grades of pig iron, and for this reason, and also because of high production costs, a limited programme for the construction of low-shaft furnaces has been agreed. Attention is also being paid to the various possible methods of so-called direct steel production, *i.e.*, ore reduction at low temperature, and some experiments have been made in Austria to develop an economically sound process.

EVOLUTION OF STEEL PRODUCTION

So long as the main product of iron-ore smelting was low-carbon 'blooms,' no steelmaking process in the modern sense was required. It was only necessary for the different users to separate the parts of the blooms with different carbon contents, or, by repeated welding, to mix them intimately, and to squeeze out the slag. Thus the tool and arms smiths usually brought the blooms direct from the *Stückofen*, and hammered them into the required shape. The increasing, and eventually exclusive, production of liquid high-carbon pig-iron made it necessary to devise improved refining processes, as only a small part of the pig iron could be made into cast iron.

The finery fire (*Frischfeuer*) has been known since the Middle Ages, and in several different forms it has been used in Austria for centuries; not until 1920 was the last Styrian finery fire at Muraü put out. About a hundred years ago students of iron-smelting in Styria had to learn the theory and practice of fourteen air-refining processes for low-carbon steel and five for higher-carbon steel. These finery fires existed in all parts of the country near the many small mountain streams (which drove the bellows and the hammers), and were even more dispersed than the blast-furnace plants. Although their consumption of charcoal was high, they produced the excellent steels that brought world-wide fame to Austrian weapons; scythes, sickles, and tools of all kinds, and also weldable chain links and chainmail.

With the invention by Henry Cort of the puddling process, which gave so great an impetus to British steel production, finery fires in Austria were gradually superseded. The Austrian contribution to the development of the puddling process lay in the successful use of brown coal in place of bituminous coal, and in the production of higher-carbon steel from puddled iron, in the works at Frantschach and Donawitz. The erection of puddling plants was hastened by the increasing demand for steel for the new machines and growing railways, which could not be met by the older processes. The Donawitz works began in 1836 as a puddling plant with an adjoining fabrication works.

The effect of the invention of the Bessemer process in 1855 was soon felt in Austria. The well-known Austrian teacher of ferrous metallurgy, Peter Ritter von Tunner, quickly recognized the importance of the invention, and at his instigation the first Bessemer converter in Austria was erected at Turrach, in Styria, in 1863. Other Bessemer plants were soon in operation in many parts of Austria, and many improvements were made, such as the use of the detachable bottom at the Neuberg works in Styria. The work of the British metallurgist Joseph Hall is well remembered in Austria, since he started the first complete Bessemer plant at the rail-rolling mills of the *Südbahn* (Southern Railway) at Graz, and drew up the plans for another plant at Ternitz.

Despite such initial successes, it soon became clear that Austrian pig iron was not really suitable for the Bessemer process. It had to be made with an unnaturally high silicon content, to be suitable for blowing, and this could be achieved only by running the blast-furnace abnormally hot, with consequent increased fuel consumption. When, therefore, the invention of the open-hearth process in 1864 made possible the manufacture of good-quality steel from high-manganese low-silicon pig iron and steel scrap, Austrian metallurgists at once realized its importance to their country. As early as 1868 the first open-hearth furnace in central Europe was started at Kapfenberg, but it ran into various technical difficulties and had to be closed after about six months' operation. However, during the next few years several other open-hearth steelworks were built, among which Donawitz rapidly gained a leading place; the construction of what was then the largest integrated open-hearth steelworks in Europe was begun in 1899. The introduction of the pig-and-ore process on a basic bottom made it possible, even with very high percentages of pig, to produce steel that was qualitatively superior to Bessemer steel in several ways. As a result, the Bessemer process, after a brief but flourishing life in Austria, declined and finally completely disappeared. The invention of the basic Bessemer process in 1878 was in no way important to the Austrian industry, because none of the local ores contained a high percentage of phosphorus. Hence, until recently the large-scale steel production in Austria has been based almost entirely on the open-hearth process. However, the very recent development of the oxygen-blown converter, with which successful results have already been obtained, may to some extent modify the dominant position of the open-hearth process.

The manufacture of high-quality steel has always

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been a large item in Austrian steel production. For example, Martin Miller started the manufacture of watch-springs from crucible steel in Vienna in 1783; his son founded a crucible-steel foundry with Daniel Fischer at St. Aegyd am Neuwald; and in 1854, at the Kapfenberg works, Franz Mayr converted the old plant (known as Erlachhammer) into a crucible-steel plant, thus laying the foundations of the development of the Kapfenberg works, world-famed as makers of special steels. In the special-steel works at Reichraming on the Enns, tungsten steel was invented by Jakob and Köller in 1855, thus initiating the development of alloyed tool steels. In another direction the importance of electric steelmaking was soon realized. The first arc furnaces in Austria were put into operation in 1908; soon after the First World War some high-frequency furnaces were installed, and an 8-ton furnace (the largest up to that time) was built at Ternitz. Electric steelmaking has now completely superseded the crucible process in Austria, and comprises about 16% of the total raw steel production. All types of constructional and tool steels, as well as special steels such as corrosion-resistance chromium–nickel steels and welding electrodes, are made in the Austrian electric steelworks, and much internationally recognized development work has been carried out. Austrian wear-resistant rail steels also have gained a wide reputation. Apart, therefore, from the increasing proportion of steel production in the oxygen-blown converter, the large-scale requirements for plain-carbon steels are met in the big open-hearth steelworks at Donawitz and Linz (the latter containing 200-ton furnaces), and in the works at Kapfenberg, Ternitz, Diemlach, Judenburg, and Liezen. At the same time, the works at Kapfenberg, Donawitz, Linz, Ternitz, Judenberg, Liezen, and Breitenfeld, make electric steels in arc and high-frequency furnaces to meet the large requirements of special steels. During the Second World War a number of electric steelworks, including the representative Marein works of Gebr. Böhler and Co. A.G., were destroyed, but since then much rebuilding has taken place, and special-steel capacity has risen again to its prewar figure.

DEVELOPMENT OF STEEL FABRICATION

Since the days of Noric iron, Austria has been famous for its finished steel products. The wrought iron and the refined blooms from the finery fires were processed in a large number of forging and wire-drawing works, and later in rolling-mills, all over Austria. In 1446, Arnold Taübenprunner, a maker of chainmail, built for himself a fine house at Kapfenberg where the Böhler works are now situated. At the beginning of the 16th century the family of Sebald Pögl, with its works at Bruck an der Mur in Styria, and in the neighbouring valleys, supplied Emperor Maximilian I with arms and war equipment of all kinds. Round the blast-furnace works (and particularly around the Styrian ore mountain), finery fires and forges and, later, many steelmaking and fabricating plants, grew up all over the valleys. The circle of influence of the Styrian ore mountain spread far into Upper and Lower Austria, leading to the establishment of scythe, sickle, knife, and cutlery forges, and frequently the names and families of the owners are the same today as they were centuries ago.

The production of wire, particularly of high-class spring and rope wire, is also part of a tradition dating from olden times, and a large number of mountain railways in Europe are equipped with wire rope made in Austria. High-quality sheet production also has a long history, which will be continued with the completion of the new broad-strip mill under construction at Linz; and important sheet-galvanizing, tinning, and enamelling industries have existed for many years.

Grey iron- and steel-founding have long been established in Austria. Quality grey cast iron from the old foundry near Mariazell in Styria was famous far beyond the frontiers; everything from cast-iron gun barrels to delicate artistic castings was made there. Today, some of the foundries are independent concerns and some belong to the steelworks. The casting of ingot moulds and rolls has long been done at the iron works at Sulzau Werfen, and there is a modern foundry for spun-iron pipes at Solbad Hall in the Tyrol. Most of the steel foundries belong to the steelworks and produce all types of casting, including alloy steel castings. All manner of rolled and forged steel and grey-iron and steel castings are therefore available for the Austrian engineering industries.

ECONOMIC DEVELOPMENT

Some remarks about economic development have been made in other parts of the paper, but the following additional remarks may be of interest. As iron was one of the most valuable sources of revenue in the middle ages, and was heavily taxed, dispersal of the production centres was discouraged so as to simplify tax collection. The State would usually support works around the Styrian and Hüttenberg ore mountains, but would often try to suppress the more scattered units. This support was not always effective, and, in particular, the works at Eisenerz got more and more into debt with the iron dealers of Steyr, in Upper Austria. During the Thirty Years War it became necessary for the government to take action, and in 1625 the ironworks at Eisenerz were compulsorily amalgamated with the fabricating works and the iron merchants; a holding company called the 'Innerberger Hauptgewerkschaft,' in which all parties received shares in proportion to the value of their assets less their debts, was formed under State leadership. Although this solution was not ideal, it did save the iron industry north of the Styrian ore mountain from collapse, and the Innerberger Hauptgewerkschaft existed for two-and-a-half centuries until it merged into the Oesterreichisch-Alpine Montangesellschaft, in 1881.

The blast-furnace plants of Vordernberg did not run into such heavy debt. The town of Leoben was their commercial centre for iron. At first they only needed to establish a looser form of association, which removed to some extent the worst difficulties arising from mutual interference in mining operations. Their full amalgamation into an organization known as the *Radmeister-Communität* (Ironmasters' Association) was

achieved in 1829 by Archduke Johann, brother of Emperor Franz I, who had bought the No. II blast-furnace plant at Vordernberg in 1822. This unification made possible half-a-century of prosperity for the industry at Vordernberg, at a time when the coke blast-furnace was already appearing as a powerful competitor.

Towards the end of the 18th century, the legal restrictions on trading were relaxed and many industrial enterprises received State support; the small ironmaking and fabricating plants scattered at a distance from the two big ore mountains were able to operate profitably again and to increase in size, and a number of new businesses were also founded at that time. But their prosperity was short-lived, and, after about a hundred years, concentration around the Styrian ore mountain again became an economic necessity. The foundation of the Oesterreichisch-Alpine Montangesellschaft in 1881 brought the most important parts of the Austrian ironmaking industry,

Fig. 7—Map of central Austrian mines and iron-smelting plants, 1875.

including the two ore mountains, under one ownership, in the location where the best conditions for permanent prosperity existed. And so, one after another, the small scattered uneconomical plants ceased production and gave way to the modern high-performance large-scale plants. Figures 7 and 8 (by W. Schuster) show clearly the process of concentration that has taken place in the last 75 years.

The large mixed smelting plant at Donawitz was then built up into the main Austrian works ; a new blast-furnace works was erected at Eisenerz, and the plants at Zeltweg, Kindberg, and Neuberg were modernized. The works at Kapfenberg was initially merged into the Oesterreichisch-Alpine Montangesellschaft, but was later transferred to Gebr. Böhler and Co. A.G., who developed it into a special steelworks. The Steirische Gusstahlwerke A.G. at Judenberg was founded in 1906, and soon attained an excellent reputation for its special steels. The works of Messrs. Schoeller at Ternitz, and those of Gebrüder Bleckmann

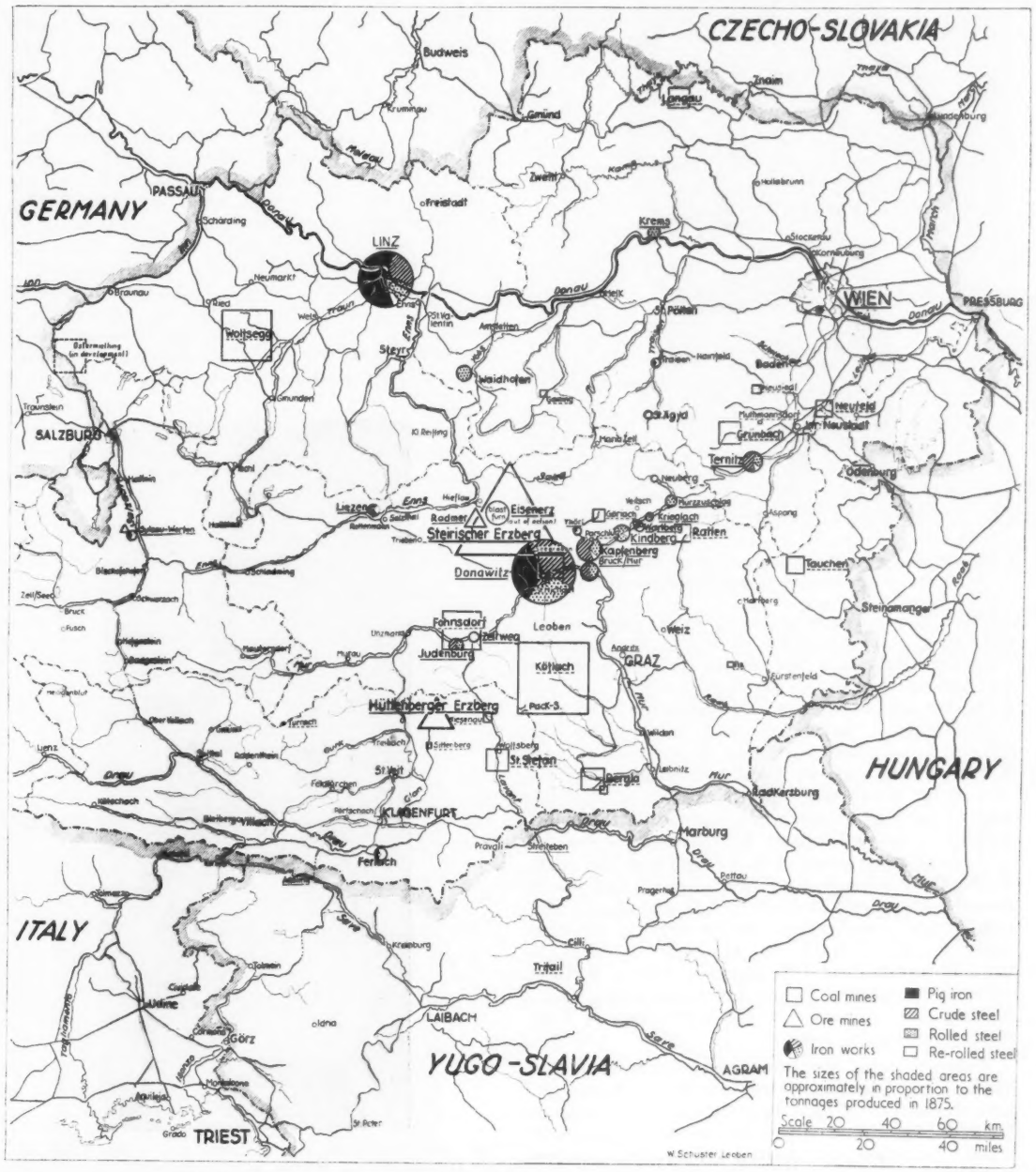

Fig. 8—Map of central Austrian mines and iron-smelting plants, 1950

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Fig. 9—Peter Ritter von Tunner (1809–1897) at the age of 39. (After the lithograph by Eybl, 1848)

at Mürzzuschlag, both long established in special-steel production, amalgamated in 1924 to form the Schoeller-Bleckmann Stahlwerke A.G. The Felten und Guillaume A.G., at Bruck an der Mur, achieved independence of outside steel supplies for its production of special wire and cables by building its own steelworks at Diemlach ; this firm, together with Johann Pengg A.G. at Thörl, near Aflenz, and the St. Egydier Eisen- und Stahl Industrie A.G., produces most of the high-quality wires required for the manufacture of the well-known Austrian wire ropes. A number of other firms, such as Vogel und Noot A.G. at Wartberg, Eisenwerke Krieglach A.G., and Kärntnerische Eisen- und Stahlwerke A.G. at Ferlach, have a high reputation in their various fields of manufacture ; mention should also be made of the long-established Stahl- und Temperguss A.G. in Traisen, and the Oesterreichisch-Schmidtstahlwerke A.G., Vienna, who specialize in the production of high-quality reinforcing bars.

Reference must also be made to the most modern works, the Vereinigte Oesterreichische Eisen- und Stahlwerke A.G. at Linz, Hütte Liezen G.m.b.H., and Schmidhütte Krems A.G. The works at Linz will, when completed, be Austria's first large modern integrated plant complete with its own coke ovens, the other two plants being a steel and grey-iron foundry, and a quality sheet mill.

The Oesterreichisch-Alpine Montangesellschaft, the Vereinigte Oesterreichische Eisen- und Stahlwerke A. G., Gebr. Böhler and Co. A.G., Schoeller-Bleckmann Stahlwerke A.G., Steirische Gusstahlwerke A.G., Hütte Liezen G.m.b.H., Kärntnerische Eisen- und Stahlwerke A.G., and Eisenwerke Krieglach A.G., are all now nationalized.

STEEL QUALITY AND THE METALLURGIST : THE AUSTRIAN TRADITION

The pure ores and charcoal available in Austria provided from the earliest times the basis of a high-quality iron and steel industry, and made a vital contribution to the establishment of the Austrian tradition of quality and craftsmanship. With the growth of iron and steel industries in other countries, and with the increasing application of new scientific knowledge and engineering techniques during the 19th century, it became necessary to develop improved methods in Austria and to provide means for research and for the technical training of the new generation of Austrian ironmasters and steelmakers.

Early in the 19th century, Technical Universities began to appear in Austria, and the Styrian State Mining and Metallurgical Academy (*Steiermärkisch-Ständische Montanlehranstalt*) was formed at Vordernberg under the patronage of Archduke Johann, and

Fig. 10—Cast-iron stove, from the Monastery St. Lambrecht in Styria, cast at foundry near Mariazell in 1757

developed in 1849 into the Montanistische Hochschule at Leoben.

In 1833, von Tunner (*see* Fig. 9) was appointed, at the age of 24, the first Professor of Ferrous Metallurgy, and Director of the Academy. He was sent, for about five years, to study the methods of all the leading ironmaking countries before he started on his teaching career. After a few years he succeeded in gaining an international reputation for his school, and many foreign students came to study there. He established the idea that the school must be in close touch with the practical problems of the industry, and must be a centre where research on such problems is carried out and discussed. In recognition of his contribution to the science of metallurgy and its teaching, he was awarded the Bessemer Gold Medal of The Iron and Steel Institute in 1878.

The Montanistische Hochschule has taken over this tradition as a cherished inheritance, and feels that it has maintained it in no small degree in the ensuing 100 years. It has always been the policy of the Hochschule to include the most experienced Austrian metallurgists among its teachers, and to co-operate closely with the Austrian iron and steel industry in the solution of its long-term and short-term technical problems.

ART AND THE AUSTRIAN IRON INDUSTRY

The tradition of skill, quality, and craftsmanship, which runs through the whole history of the Austrian iron and steel industry, has also been expressed for many generations in beautiful examples of ornamental cast and wrought iron. The social pattern of the middle ages and of the 17th and 18th centuries in Austria, with large wealthy families who could afford the money and leisure to give patronage to the arts, encouraged succeeding generations of craftsmen to produce works of art of unrivalled beauty. The picture of the Austrian iron and steel industry would therefore be incomplete without some examples of these works of art.

Fig. 11—Baroque wrought-iron grille from the Pilgrim Chapel at Mariazell, in Styria. About 1700

Fig. 12—Modern wrought-iron grille at the Benedictine College of St. Peter, Salzburg, 1926

A very fine cast-iron stove from the monastery at St. Lambrecht is shown in Fig. 10; the ornamental parts of this stove were cast in 1757 in the foundry near Mariazell. Figure 11 illustrates the ornamental wrought-iron grille from the Pilgrims' Chapel at Mariazell, dating from about 1700.

The ornamental wrought-iron industry has maintained its tradition of skill and artistry into modern times, as can be seen from Fig. 12,* which shows a wrought-iron grille, dating from 1926, that is in the Benedictine College of St. Peter at Salzburg.

Thus it can be seen that 2000 years of technical development, and an equally ancient culture, have provided the fertile soil in which the modern Austrian iron industry flourishes today.

Acknowledgments

The author would like to express his sincere thanks to Dipl.-Ing. W. Schuster for all the help he has given and for placing his wide historical knowledge so unreservedly at the author's disposal.

* "Die Oesterreichisch-Alpine Montangesellschaft, 1818–1931," p. 42, Fig. 32. Wien, 1931 : Julius Springer.

XUM

Investigations into the Effect of Non-Metallic Inclusions on the Hot-Workability of Steel

By F. Rapatz and M. Strobich

SYNOPSIS

Forging tests on mixtures of iron powder with various proportions of the non-metallic inclusions CaO, SiO_2, CaF_2, Na_2CO_3 and Na_2SiO_3, showed that the lower the melting point of the included material, the greater is the difficulty in hot-working, irrespective of whether the inclusions are acid or basic. The poor forgeability of steel containing acid inclusions is attributed to the low melting points of the silicates in the added material.

It is found that bars prepared from steel powder by hot-working have almost the same mechanical properties as those prepared by casting and rolling.

Introduction

THE rolling capacity and forgeability of steel, *i.e.*, at what temperature steel should be subjected to deformation, and whether the deformation should be effected rapidly or slowly, depends mainly on its chemical composition. It is usual to ascribe difficulty in hot-working to the effect of non-metallic inclusions; cracking mainly occurs more or less like red-shortness. There are many references in the literature[1, 2, 3, 4, 5, 6, 7] to sulphur as a cause of cracking, but it is not the only element that causes bad hot-workability. Other inclusions can have the same effect, and can also be the cause of phenomena like red-shortness, and of many defects that occur during forging and rolling.

This paper gives the results of some investigations, and indicates the nature and quantity of inclusions that a steel can tolerate without prejudice to its hot-workability, although no final conclusions are drawn.

EXPERIMENTAL DETAILS

Materials and Apparatus

Non-metallic compounds were added arbitrarily to the steel, starting by mixing various quantities with iron powder. The iron powder, which was prepared by the centrifugal method of the Deutsche Pulvermetallurgische Gesellschaft, Frankfurt-am-Main, contained about 3% of oxygen and about 2% of carbon, and its grain size was less than 0·3 mm. A detailed description of the process is given by R. Kieffer and W. Hotop.[8]

The powder was used as prepared, and not in the reduced state; its composition was such that, on being heated to about 1200° C., soft steel was formed by the reactions $FeO + C = Fe + CO$, and $2FeO + C = 2Fe + CO_2$. A primary consideration was that this powder is relatively cheap, and that the process might be used to make articles composed of iron powder and other constituents. Quantities of CaO, SiO_2, CaF_2, Na_2CO_3, and Na_2SiO_3, of grain size less than 0·1 mm., were each mixed with the iron powder. These additions contained less than 3% of impurities; in assessing their effects on forgeability it was considered advisable to calculate their proportion in percentages by volume rather than by weight. The powder mixtures were packed into steel tubes of 2 in. dia., 14 in. long, and of $\frac{1}{8}$ in. wall thickness. The two ends of the tubes were sealed by welding to them plates of similar thickness: in each case, a 1-mm. dia. hole was made in the cover plate, to allow the escape of gases formed during the reactions.

Manuscript received 16th April, 1951. Mr. Rapatz and Mr. Strobich are at Gebr. Böhler and Co. A.G., Kapfenberg, Austria.

Method

The filled tubes were heated for 25–30 min. at 1250° C. in a gas-fired furnace, this period being sufficient to complete the reaction between the iron oxides and the combined carbon. The specimens were then given their first deformation by stamping in a die at a temperature of 1200° C.; complete consolidation in the transverse direction was achieved with only slight lengthening. The bars so obtained were subjected to further deformation by free forging.

Small 2-in. specimens, not containing non-metallic additions, could be forged without difficulty at temperatures of 1100–800° C., whether or not the tubular sheath had been machined away after the specimen had been die-stamped. Tensile test pieces, prepared from forged specimens after removal of the tubular sheath, had the following mechanical properties in the normalized condition:

Yield point, tons/sq. in.	19	(30 kg./sq. mm.)
Tensile strength, tons/sq. in.	25·5	(40 kg./sq. mm.)
Elongation, % ($l = 10d$)	23	
Reduction in area, %	60	

These values differ very little from the corresponding values for a cast steel also containing 0·1% of carbon.

In further experiments, non-metallic materials were added to the iron powder and the tubes were also sintered at 1250° C. for about 30 min., and then forged down to 2 in. dia. at temperatures between 1100° and 800° C. unless cracks occurred before this could be done.

Although these results cannot be applied directly to cast steel, the experiments show the relative effect of the various pure non-metallic substances, with the reservation that the inclusions probably do not

remain in the pure form in which they are added, but take up some iron oxides.

EXPERIMENTAL RESULTS

Addition of Calcium Oxide—The addition of up to about 7% by volume of CaO has no deleterious effects on hot-workability; the specimens could be forged down to about 2 in. without special precautions. If 7–9% of CaO is added, it is still possible to forge, if care is taken not to hit hard. CaO has a melting point of 2570° C., and introduces difficulty in hot-working only when it is present in considerable amount.

Addition of Silica—When up to 6·6% by volume of SiO_2 was added, the workability remained good; after adding 9% by volume, forging was still possible with care. Silica (melting point about 1450° C.) behaves like calcium oxide because of its high melting point. This might seem to be contradicted by the fact that acid steel, *i.e.*, steel in which acid inclusions predominate, is usually more difficult to hot-work than basic steel.[9, 10] However, in acid steel, the inclusions do not consist of pure SiO_2, but are mostly silicates with relatively low melting points. That these silicates can be readily fused is shown by their plastic behaviour when hot-worked, and by the fact that they can be drawn, just like sulphide, into strips and threads, in contrast to basic inclusions which usually crumble when hot-worked.

Addition of Calcium Fluoride—Good workability is possible with additions of up to 8% by volume of CaF_2. The melting point of pure fluorspar is about 1390° C.

Addition of Sodium Carbonate—Even with the addition of as little as 1½% by volume of Na_2CO_3, it is impossible to forge specimens to less than 5-in. dia., since cracks occur in the planes of weakness. The pronounced effect on forgeability of additions of sodium carbonate results from its low melting point (about 850° C.).

Addition of Sodium Metasilicate—The forgeability, after adding Na_2SiO_3, is similar to that of specimens with additions of Na_2CO_3. Na_2SiO_3 also has a low melting point (1027° C.).

Cracks occur when low-melting-point additions are incorporated because, as in the case of red-shortness, steel cracks along the surfaces where liquid or greatly softened substances are present; with high-melting-point inclusions, the steel in deforming flows round the inclusions, without leaving discontinuities. Figure 1 shows the consolidation of iron powder, containing about 9% of SiO_2, into a non-porous compact, after forging down to one-third of the original cross-section.

SUMMARY AND CONCLUSIONS

(1) Forging tests on mixtures of steel powder with various non-metallic substances showed that the lower the melting point of the non-metallic inclusion, the greater was the difficulty in hot-working, irrespective of whether the inclusions were basic or acid.

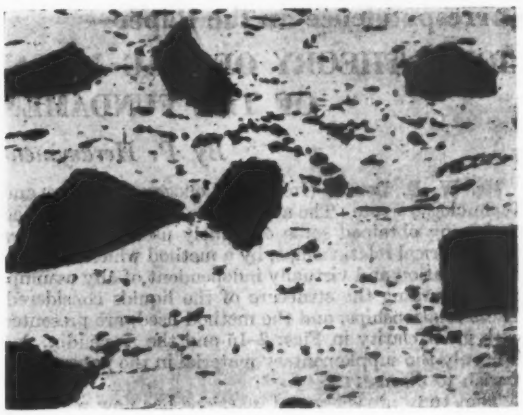

Fig. 1—The flow of steel round inclusions × 120

(2) The addition of up to approx. 6% by volume of high-melting-point inclusions did not cause internal cracks under the experimental conditions; the behaviour, as regards forgeability, was like that observed when carbides are added.

(3) Non-metallic compounds with low melting points *e.g.*, Na_2CO_3 and Na_2SiO_3, even when present to the extent of only 1½% by volume, make hot-working impossible.

(4) The occasional poor forgeability of steel with acid inclusions is attributed to the low melting point of silicates in comparison with that of basic inclusions. Pure SiO_2 has a high melting point, and only renders hot-workability difficult when present in large amounts.

(5) Bars prepared from steel powder by hot-working have almost the same mechanical properties as those prepared by casting and rolling.

(6) There would seem to be a variety of possible new applications for hot-worked steel powder mixed with non-metallic additions.

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XUM

Correspondence on the Paper—

IONIC THEORY OF SLAG–METAL EQUILIBRIA: Pt. I—DERIVATION OF THE FUNDAMENTAL RELATIONSHIPS*

By P. Herasymenko and G. E. Speight

Mr. **W. E. Dennis** (Imperial College of Science and Technology) wrote: The authors are to be congratulated on having obtained some extremely useful correlations and empirical relationships, by a method which is simple in application and virtually independent of any assumptions regarding the structure of the liquids considered. These relationships, and the method used, are presented with great clarity in Figs. 2–15 and the Appendix, and it is only the supplementary material in the paper which I wish to discuss.

The study of slag–metal reactions has now reached a stage at which four direct methods of investigation are being used:

(i) Measurement of total concentrations present in the slag and metal phases at equilibrium. (The data used in this paper were obtained by this method)

(ii) Thermodynamic measurements giving activity coefficients. This enables a wide range of conditions to be calculated with certainty from a relatively small amount of experimental data

(iii) Electrochemical studies which, by providing conductivity, transference, and mobility data, should enable us to calculate with certainty ionic concentrations and diffusion coefficients, and also to obtain reaction mechanisms and activity data from cell E.M.F.

(iv) Kinetic studies, which provide data on reaction mechanisms as well as diffusion coefficients.

The great majority of published results were obtained by method (i), which yields the type of data most difficult to describe in terms of parameters having a fundamental significance. They are in the majority because they are the easiest to obtain experimentally, and because, hitherto, the industrial processes have been controlled and the products specified in terms of the total concentrations. Theoretical treatment of this type of data has produced many valuable extensions and correlations of the experimental results, together with many lengthy and erroneous speculations on the constitutional nature of these liquid phases and the laws governing the distribution of their components.

It seems unfortunate, at this stage of development of the subject, that the excellent method presented by the authors should contain so many references to the electrochemical nature of slags. For example, the equation: $Fe + Mn^{++} = Mn + Fe^{++}$, as used by the authors, could be simply justified by the condition of electroneutrality, whereas if, as instructed, the authors' original derivation of this relationship is referred to,† we are confronted with some unusual equations for electrochemical potentials, in which the standard electrode potential is independent of the cation considered.

Their use of thermodynamic nomenclature to describe correlating parameters is also rather unfortunate. In their considerations of the distribution of iron and oxygen between the two liquid phases at equilibrium, the authors have shown quite clearly that the 'concentration ratio constant' can be correlated with $A(O'')^{3/2}$, where A is a constant varying only with the temperature. But in their derivation of equation (11):

$$f_{Fe}{}^{++} = \frac{K'}{(O'')^{3/2}}$$

for the variation of the activity coefficient of iron in the slag with the oxygen content of the slag, they have assumed that oxygen behaves ideally in both phases, and have not defined any limits for their assumption. Thus they have assigned the term 'activity coefficient' to a correlating coefficient which, though completely valid as such, should not be confused with the thermodynamic coefficient, which may have quite a different value and significance.

Reference to the recent symposium of the Faraday Society‡ reveals that even the terms ion, atom, and molecule, as applied to slags, are becoming quite loosely defined; it seems that the time has come when speculation, empirical relationships, and fundamental science, should be rigidly separated, lest in the end we be confronted by 'uncharged ions' in 'semi-regular solutions.'

AUTHORS' REPLY

Dr. **Herasymenko** and Mr. **Speight** (The United Steel Companies, Ltd.) wrote: The field we wished to cover in our paper is so wide that we could not afford much space for a detailed discussion of the published information on the electrochemical nature of slags. However, the present state of electrochemical studies is not sufficiently advanced to allow the direct determination of ionic concentrations, or direct measurement of thermodynamic properties, of such complex solutions as molten slags.

The constancy of the activity coefficients of oxygen and sulphur anions was deduced from the constancy of the equilibrium ratio k_s^o. This assumption is valid for the range of slag and metal compositions covered by the experimental data of Chipman and his co-workers, *i.e.*, for basic slags containing approximately 0·03–0·50 (O'') and up to 0·0015 (S''), and for liquid steel containing up to about 0·25 [% O] and up to 0·10 [% S]. The activity coefficients used in our paper describe the deviations in the behaviour of ions from the ideal laws, and thus have the same thermodynamic meaning as the activity coefficients used in theories of other types of solution. The fact that the activity coefficient of ferrous ions can be correlated empirically with the concentration of oxygen anions does not deprive this activity coefficient of its thermodynamic significance.

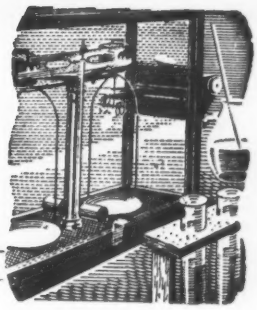
* *Journal of The Iron and Steel Institute*, 1950, vol. 166, pp. 169–183.

† P. Herasymenko: *Transactions of the Faraday Society*, 1938, vol. 34, pp. 1245–1257.

‡ Symposium on the Physical Chemistry of Process Metallurgy, *Discussions of the Faraday Society*, 1948, No. 4.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Production of High-Purity Iron and Iron Alloys on a 25-lb. Scale

By B. E. Hopkins, M.Sc., G. C. H. Jenkins, and H. E. N. Stone, B.Sc.

SYNOPSIS

The method and equipment developed in the National Physical Laboratory to produce iron and iron alloys of high purity as 25-lb. ingots are described. Starting with a selected batch of Swedish iron, the purification procedure is carried out on the iron in the molten condition in two main stages: (*a*) oxidation of a number of impurities and removal of the products of oxidation, and (*b*) a vacuum treatment for degassing, followed by reduction of oxygen to a low level by dried hydrogen. The experience gained in operating the process over a period of time is recorded. Chemical analyses of the iron before treatment, of the oxidized iron, and of the reduced iron, are given. Some investigation has been necessary into methods of analysis and notes on these are given in an Appendix.

Introduction

THE extensive mechanical tests involved in a programme of research being undertaken at the National Physical Laboratory on the effect of alloying elements on the mechanical properties of iron, with particular reference to the effect of temperature, mode of deformation and failure, and the transition from a tough to a brittle fracture, require substantial quantities of iron of reasonably high purity. A supply of such iron was not available commercially, and consideration had to be given to producing it in suitable form in the Laboratory.

By combinations of chemical and metallurgical methods, iron of very high purity has been produced in the past, Adcock and Bristow[1, 2] of the National Physical Laboratory and Cleaves and Thompson[3] of the U.S. National Bureau of Standards being notable workers in this field. Adcock and Bristow produced ingots of high-purity iron of up to 7 lb. in weight, but the relatively large samples necessary for chemical analysis and other research requirements at that time left insufficient material for comprehensive mechanical tests. Their methods are not readily adaptable for expansion to the scale required in this work under the conditions existing in a normal metallurgical laboratory. For the present purpose, it was considered desirable to produce high-purity iron ingots weighing about 25 lb. each. It was realized that some sacrifice might have to be made in the purity that could be obtained, and, initially, a general target was set of not more than 0·01% of any one impurity, with considerably less than this of certain impurities known to have deleterious effects in small proportions.

To avoid the necessity of using chemical methods of purification on the required scale, a search was made for an iron which contained no impurities that could not be reduced by metallurgical methods to within the stated limits. Twenty-five cwt. of iron of the following average composition was eventually obtained from Hellefors Bruks Aktiebolag, Sweden:

Impurity	Amount Present, %
Carbon	0·015
Silicon	0·016
Manganese	0·008
Sulphur	0·006
Phosphorus	<0·001
Nickel	0·005
Chromium	0·0025
Copper	0·006
Aluminium	<0·001
Oxygen	0·044
Nitrogen	0·01
Hydrogen	trace

It is believed that this material was made from selected ore, and refined in electric furnaces. It was supplied as 4-in. square billets, ½-in. round bars, and 5-mm. strip.

Paper MG/A/220/50 of the Alloy Steels Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 16th December, 1950. The views expressed are the authors' and are not necessarily endorsed by the Committee as a body.

Mr. Hopkins and Mr. Jenkins are in the Metallurgy Division of the National Physical Laboratory, Teddington, and Mr. Stone, who is on the staff of the British Iron and Steel Research Association, is at present working at the National Physical Laboratory.

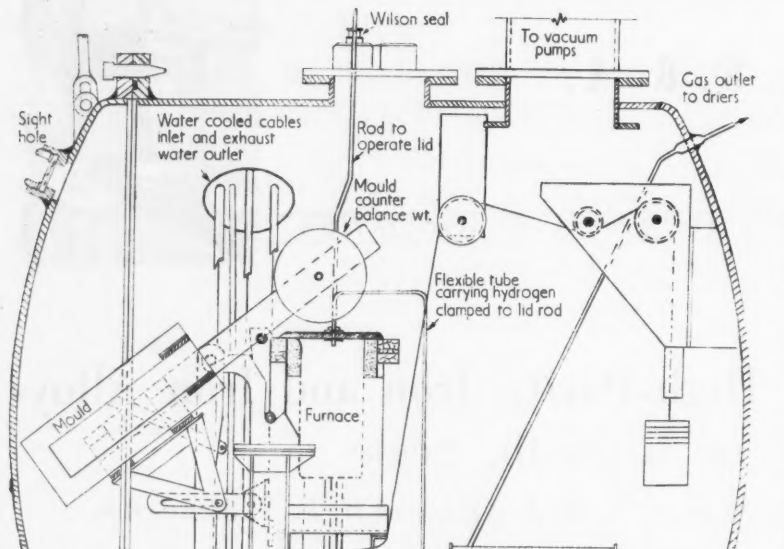


Fig. 1—Section through mild-steel tank surrounding furnace

By melting the iron in air, the proportions of the readily oxidizable impurities present can be reduced to low values, and the excess oxygen can be removed by subsequently melting in hydrogen. This purification procedure has little effect on the nickel and copper contents, and the manganese content is thereby only partly reduced. The carbon, silicon, and chromium contents are decreased by the oxidation process, and limited success is achieved in reducing the sulphur content. The oxygen and nitrogen contents are reduced to low values by melting in hydrogen.

APPARATUS

The melting equipment acquired for this work consists of two high-frequency induction furnaces, one a 75-lb. tilting furnace in which the first part of the process—the melting under oxidizing conditions—is carried out, and the other a 25-lb. furnace in which the second half of the process—the melting under hydrogen—is done. Both furnaces are operated by a 30-kW. motor generator set, delivering power at a frequency of 5000 cycles. A cut-out switch is set at 660 V. and 54 amp. The cooling water operates a relay on each furnace, which switches off the power if the water pressure is insufficient. Below the coil in the Sindanyo base of the 75-lb. furnace is a charge-earthing device, which switches off the power in the event of the melt breaking through the lining.

The method developed for lining the 75-lb. furnace has proved entirely satisfactory in that the lining is completely reliable in holding the metal, has a reasonable life, and effects some purification of the charge without any contamination. The coil, which is 12 in. high and of 9 in. internal dia., with 20 turns, is plastered on the inside to a thickness of about $\frac{1}{4}$ in. with a 3 : 2 sillimanite–Ciment Fondu mixture, the thickness at the bottom of the furnace being about 1 in. The first lining material used was high-purity fired magnesia, which was fritted without a binder by the usual method of ramming it around a mild-steel former, and melting the former with a scrap charge of iron. As the spout and the top of the lining above the coil could not be sintered by heat from the charge, the magnesia in these regions was bonded with sodium silicate. This lining only sintered at the surface, and was sufficiently porous to absorb iron oxide readily, resulting in further strengthening: it cracked on repeated heating and cooling, but this did not affect its performance, because it sintered immediately behind the cracks.

Magnesia, if required with a low sulphur content as in this work, has the disadvantage of being almost prohibitively expensive at present. Further linings in the 75-lb. furnace have therefore been made from fired magnesite, used without adding a bond, and sintered in the same way as described for magnesia. The magnesite contained about 17% of lime, less than 5% of silica, and was very low in sulphur. It sinters eventually through most of its thickness, and is regarded as satisfactory, especially as no contamination of the melt occurs.

The ingot mould used with the 75-lb. furnace is split; it is made of mild steel, and is of 4 in. internal dia. and 7 in. external dia., and 24 in. long. No dressing is applied to its internal surface, and provided care is taken that the stream of molten metal is directed on to the existing pool and not on to the side of the mould, no trouble is experienced with sticking or 'burning-on' of the ingot.

The 25-lb. furnace shown in Fig. 1 is enclosed in a horizontal cylindrical mild-steel tank, 4 ft. in dia. and 4 ft. 6 in. long, the end of which is closed by a domed lid, the seal between the two being maintained by a tongue and groove with an intervening rubber ring. The tank is evacuated through an 8-in. dia. pipe by two rotary pumps, which can be operated in

series or in parallel. The pumps have capacities of 120 cu. ft. and 60 cu. ft. swept volume per min., and can be isolated from the tank by means of a valve in the 8-in. pipe: this valve has been described elsewhere by Atkins and Jenkins,[4] and was designed so that the rate of evacuation of the tank can be controlled easily.

The furnace can be tilted by a chain and cog arrangement, which is operated by a shaft passing through a vacuum-tight gland in the tank wall to a handle on the outside. A separately counter-balanced mould, suitably placed in front of the furnace, is made to tilt with the furnace when the metal is poured at the end of a run. The leads to the furnace coil are flexible, and are covered with rubber tubing of ¼-in. wall thickness, to provide insulation and to carry the cooling water. The leads enter the tank through an insulating plate, the necessary seals being made with clamped rubber rings.

One of the three openings on top of the tank is closed by a glass plate and is used to inspect the melt from above. A second opening is fitted with a Wilson seal,[5] through which passes a rod to which the refractory lid of the furnace is attached. The lid can be turned, or raised and lowered, by means of this rod without leakage of air into the tank. The third opening is fitted with the eccentric sliding valve shown in Fig. 2, which consists of two circular plates with off-centre holes that can be matched by relative rotation of the plates over their lapped contact faces, the hole in the bottom plate being vertically over the third opening in the tank. A sheathed thermocouple placed in a Wilson seal screwed into the hole in the top plate can be lowered into the melt, after rotating the plate from its sealing position into that for which the holes in the two plates and the tank are coaxial. By replacing the thermocouple sheath by a dip-stick, samples of the melt at various stages of purification may be obtained. Additional sight-holes are provided in the lid and on one side near the tilting wheel, enabling the pouring operation to be viewed from the outside.

Figure 3 shows schematically the arrangement of auxiliary equipment for the 25-lb. furnace and the course of the hydrogen flow during the reduction process. Dried hydrogen is drawn into the tank by a small rotary pump, and is passed through a filter and a tube leading through the crucible lid on to the

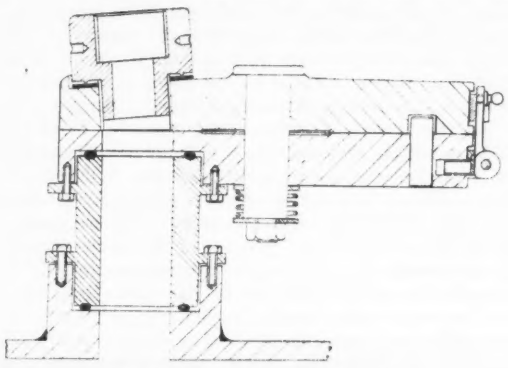


Fig. 2—Eccentric sliding valve

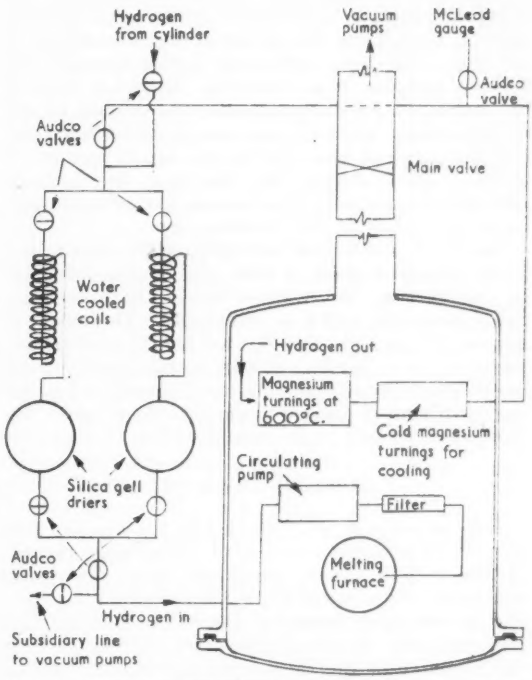


Fig. 3—Auxiliary equipment for the 25-lb. furnace, showing hydrogen flow

surface of the melt. Water vapour is formed by reaction of hydrogen with the oxygen in the iron, and the moist hydrogen is drawn out of the tank through a furnace containing magnesium turnings at 600° C., to remove nitrogen, and then through a cooler consisting of a cylinder containing cold magnesium turnings. Outside the tank, the hydrogen passes through a water-cooled coil, in which a small amount of the water vapour may condense, and into a large cylindrical drier containing 7 kg. of silica gel. A second similar cooling and drying train is used in the later stages of a run to effect final drying of the hydrogen. The capacity of the circulating pump is 120 cu. ft./hr., and the volume of the tank, 50–60 cu. ft.

The magnesium turnings used to absorb nitrogen are replaced after every three melts. The silica gel is reactivated after each melt by passing air dried with calcium chloride through the drier as it is heated slowly to 300° C. by an internal electric heater. The small amount of water which may condense in the cooling coils can be run out through a tap at the bottom of each coil.

The furnace coil is plastered with a sillimanite–Ciment Fondu mixture as for the 75-lb. furnace. The substantial amount of water used in making this cement has to be removed by baking in air when it is first applied, otherwise it evaporates during melting, so that an unduly long time is spent in drying the hydrogen and hence in deoxidizing the iron. Melting is carried out in a 4¾-in. dia., 9½-in. long, sintered high-purity alumina crucible, which is packed all round with the same fired magnesite that is used to line the 75-lb. furnace. The top inch of packing is bonded with sodium silicate, so that it sets

at room temperature and prevents the loose packing beneath from being drawn out during evacuation of the tank, while being sufficiently porous to enable air and any moisture to be removed. The main body of the packing is eventually sintered right through by the molten charge. Six melts are commonly made in each alumina pot, and although the pot cracks because of thermal shock during the first run, the packing prevents outward seepage of metal, so that the cracking of the pot is of little consequence.

The ingot mould that has been mostly used in the 25-lb. furnace is made of mild steel, and is octagonal in cross-section, the distance across the flats being $2\frac{3}{4}$ in. internally and 6 in. externally. The mould is approx. 15 in. high, and the top 3 in. is turned out internally to a diameter of 4 in. to take a sillimanite insert, which operates as a hot top. Recently, a tapered mould of similar general design has been used. No dressing is applied to the mould surface.

OXIDIZING MELTS

Prior to being melted in the 75-lb. furnace, the base iron is thoroughly cleaned of extraneous matter. Melting a 75-lb. charge takes about $1\frac{1}{2}$ hr. The metal is allowed to oxidize in the molten condition for 1 hr., and the iron oxide formed on the surface is continually skimmed off. In the early stages of this work, it was found that the carbon content of the oxidized melts was not usually reduced below about 0·007–0·009%, the oxygen content being 0·2–0·3%. This carbon range is less than that calculated from the value, given by Vacher and Hamilton,[6] of 0·011 at 1620° C. and at a pressure of 1 atm. of carbon oxides for the [C] × [FeO] product, using weight percentages. It is likely that the carbon monoxide from the C–FeO reaction is not completely removed by ordinary melting in air. This appears to be confirmed by the fact that the ingot of oxidized iron is gassy, and that the amount of carbon present can be reduced to a lower level by subsequent melting *in vacuo*, when gas is seen to be evolved. Much sounder ingots of oxidized iron (increased in density by up to 20%) are obtained by blowing nitrogen or argon on to the melt in the 75-lb. furnace, after the 1-hr. oxidation treatment, for a period of 20 min. to remove carbon monoxide. This procedure was adopted as standard practice, and it does assist in producing carbon contents of much less than 0·008%: it is not, however, as consistent in its results as the vacuum treatment applied in the 25-lb. furnace. Some of the unsoundness in the oxidized iron ingots, and the evolution of gas in the subsequent vacuum treatment, may be caused by hydrogen formed from the water vapour in the atmosphere. Experience has shown that the form of the charge influences the carbon content obtained; for example, if the Swedish iron consists of strip or rod instead of heavier sections, the carbon content of the oxidized iron is as low as 0·002%.

The oxidized melts are usually analysed for carbon, silicon, and sulphur; the majority contain amounts within the following ranges:

Carbon, %	0·002–0·005
Silicon, %	0·002–0·003
Sulphur, %	0·004–0·006

Vacuum fusion analyses of two oxidized irons gave the following average results:

Oxygen, %	0·28
Nitrogen, %	0·01

The oxidized iron ingots are skimmed to remove surface scale, and cut into lengths suitable for melting in the 25-lb. furnace.

REDUCING MELTS

The charge for the 25-lb. furnace is cleaned with carbon tetrachloride and dried, before assembling in the crucible. After the mould and its support have been clamped in position, the tank is closed and evacuation is commenced. When a new melting crucible is used, it is normal to heat the charge to about 1000° C. for a period to de-gas the refractories: after cooling, a pressure of 0·001 mm. of Hg is usually obtained. Such a 'heating run' is not conducted if the crucible has been used previously, in which case the time required to reach the limiting pressure depends on how long the tank has been open after the previous run. If melting was carried out on the previous day, the tank is opened in the morning, and evacuation for the next melt can usually be started in the afternoon: pressures of 0·005 mm. of Hg are obtained in about 1 hr., and 0·001 mm. of Hg in about 2 hr. Evacuation is continued for the rest of the day while the silica-gel driers are reactivated.

At the end of the afternoon, the pumps are shut off and the main valve is closed, to isolate the tank. By the following morning, the pressure has usually risen to $\frac{1}{2}$–2 mm. of Hg. Little of this rise in pressure is regarded as leakage; most of it is probably caused by continuous evolution of gas in the system. If, on starting the pumps and opening the main valve, the pressure is reduced to 0·002 mm. of Hg within a few minutes, the tank is considered to be substantially gas-tight. If the driers and connecting pipes outside the tank are also gas-tight, the system is ready for the melting process.

The charge is heated slowly and melts in about $2\frac{1}{2}$ hr. The tank is filled with hydrogen from a cylinder to a pressure of 10 cm. of Hg during this stage, to prevent spurting due to evolution of gas while the charge is melting. By avoiding spurting, and by increasing the clearance between the solid charge and the crucible wall, trouble due to 'bridging,' which was experienced initially, has been overcome. When the charge is all molten, the hydrogen is removed by opening the main valve connecting the tank with the pumps, and the melt is held for an hour *in vacuo* while the oxygen content is still high, to reduce the carbon content as mentioned previously. During this period, the pressure drops fairly quickly, to about 0·05 mm. of Hg and remains at this level. The pumps are then isolated from the tank, and hydrogen is introduced to a pressure of one atmosphere. The hydrogen circulating pump is started, and the hydrogen is blown on to the surface of the melt, passed through the furnace containing magnesium at 600° C., through the coolers and one of the driers, and then back into the tank. Because of the high conductivity of hydrogen, approximately twice the power is necessary to keep the charge molten as would be required *in vacuo*.

A check on the extent of deoxidation is obtained by testing the dryness of the hydrogen atmosphere by its capacity to oxidize a hot dip sample. A small length of Swedish iron is attached to the end of a rod, which is pushed through the Wilson seal on the eccentric sliding valve and is dipped momentarily into the melt to obtain a sample. The dip sample is then raised to the top of the tank, and is allowed to cool in this position for 5–6 min. before removal. If the hydrogen is dry because the oxygen content of the melt has been reduced to a low value, the dip sample is bright. If deoxidation to this extent has not been achieved, the dip sample oxidizes on the surface as it cools. The test is sensitive, in that varying degrees of oxidation of the dip sample are obtained, depending on the proportion of moisture in the hydrogen. It is thus possible to check that no leaks have developed in the system during the run. The test has not been calibrated quantitatively, since only the 'end point,' namely, the conditions under which a bright dip sample is obtained, is of interest. The oxygen content of the melt for which a yellow coloration of the dip sample is first detected is thought to be somewhat less than 0·005%, *i.e.*, less than the solubility limit in ferrite. By continuing the hydrogen treatment of the melt for ½ hr. beyond the stage at which the dip sample is bright (this usually occurs less than 1 hr. after the introduction of hydrogen into the tank) and by substituting the second drier for the first in the circulation train to achieve final drying of the hydrogen, oxygen contents well below 0·005% are obtained.

When the reduction process is complete, circulation of the hydrogen is stopped, and the pressure is reduced to 5 cm. of Hg over a period of ½ hr., so that evolution of hydrogen from the melt is controlled to avoid splashing. The melt is poured at this pressure by simultaneous tilting of the furnace and mould. The ingot is allowed to cool overnight and is removed from the tank in the morning. A hydrogen pressure much above 5 cm. of Hg causes a gassy ingot, whereas, if the pressure is much lower, there seems to be a greater tendency for the ingot to stick to the mould owing, presumably, to a less effective adsorbed layer of gas on the surface of the mould.

The temperature of the melt is checked periodically with a platinum/platinum–rhodium couple as described earlier. It has been found that, if the temperature is in the range 1565–1585° C. just before pouring, a satisfactory ingot is produced, and that no sticking to the mould is encountered, although care still has to be taken that the stream of molten metal does not impinge on the side of the mould at any one spot. An attempt is made to pour in such a way that the stream of metal does not touch the walls of the mould. This requires a little skill on the part of the operator, and although no trouble is now experienced, it is intended to make this operation less dependent on the personal element by arranging to rotate the mould a few times during pouring, either mechanically or by means of an electric motor, so that impingement of molten metal in any one position on the mould wall cannot occur. It is possible that water cooling of the mould would also stop sticking, but this method is not convenient in this case.

When making alloys, the additions are usually packed in iron sheet rolled from a deoxidized ingot, suspended from a cross-piece attached to the tube which holds the lid of the furnace, and lowered into the molten iron after it has been deoxidized. If the added element contains oxygen, the hydrogen treatment must be continued until it has been removed. Certain additions are required to be free from oxygen, because their oxides are not reduced by hydrogen at the temperatures reached in melting.

TREATMENT OF INGOT

After removing the head, an ingot is heated to a temperature of 1100° C., and is rolled in 18 passes (averaging 15% reduction), to ⅝-in. dia. bar. Reheating is normally necessary after the 7th and 17th passes, the second reheating being an attempt to complete the last pass at a temperature which does not vary widely and is sufficiently high to avoid cold work that could affect the grain size obtained after subsequent normalizing. No difficulty has been experienced in hot rolling, and forging has also been carried out satisfactorily. The yield of rolled bar after cropping at various stages is about 70% of the weight of the charge.

ANALYSES

The samples for analysis are milled in a special room from slices cut from the heads of the ingots. The surfaces of the slices are either filed or machined to a fine finish and degreased before milling. Checks have been made on the wear of the milling cutter and the amount of carbon picked up from this source has been found to be very small.

Of 35 iron and iron alloy ingots which have been analysed chemically, the majority have the following composition range :

Impurity	Amount Present, %
Carbon	0·002–0·004
Silicon	0·002–0·003
Manganese	0·004
Sulphur	0·004–0·006
Phosphorus	<0·001
Nickel	0·005–0·007
Chromium	0·001
Copper	0·004–0·007
Aluminium	0·001 or less

Occasionally, aluminium contents higher than 0·001% are obtained. These occur either when the melt has been accidentally overheated, or when the added alloying element reduces the alumina melting crucible; some iron–carbon alloys have been made with aluminium contents of up to 0·004%. Adcock[7] has shown that thoria is not attacked by iron–carbon alloys, and if alloys with larger carbon contents are made, it may be necessary to use either thoria or thoria-lined crucibles.

Notes on the methods adopted for chemical analysis are given in the Appendix.

Twenty-four ingots which have been analysed by the vacuum fusion method, were found to be mostly within the following range :

Oxygen, % by wt.	<0·001–0·002
Nitrogen, % by wt.	0·001–0·002
Hydrogen, % by wt.	trace (<0·000005)

The vacuum fusion analyses were carried out on samples prepared from material that had been hot-

rolled and normalized from 950° C., and it will be seen that the hydrogen content is very low, even though the ingots were solidified in hydrogen at a pressure of 5 cm. of Hg. The hydrogen content in the cast condition is about 0·00007% by weight.

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APPENDIX

The Determination of Impurities within the range 0·001–0·01% in High-Purity Iron

By H. G. Short, M.Sc.

An outline of the methods used is as follows:

CARBON

Principle

The sample is dissolved in acid copper potassium chloride solution. After filtration through ignited asbestos, carbon is determined in the insoluble residue by combustion in oxygen. Wells' method[8] has recently been tried and found to be satisfactory, and a slightly modified form of the apparatus will probably be adopted for future work.

Method

The weight of sample taken is varied with the carbon content, as follows:

Carbon Content, %	Wt. of Sample, g.
0·001–0·005	50
0·005–0·01	30
>0·01	10–20

Dissolve the sample in a solution of copper potassium chloride (1200 g. + 450 ml. of HCl (s.g. 1·18) + 3500 ml. of water, filtered through a sintered glass filter before use), using 50 ml. of reagent per gramme of sample. Solution is hastened by warming to 50° C., and stirring. Filter the solution through a pad of ignited asbestos, wash well with water, and dry at 110° C.; determine carbon by combustion in oxygen at 1000° C. in the usual way.

The blank on all reagents and procedures has been found to be 0·0004 g. of CO_2.

SILICON

Principle

The sample is dissolved in dilute sulphuric acid and silicon is determined directly by a colorimetric procedure based on that of Gentry and Sherrington.[9]

Method

Dissolve a 1·5-g. sample in 100 ml. of dilute sulphuric acid (s.g. 1·06), and oxidize with potassium permanganate until a small permanent precipitate of MnO_2 is obtained. Add ferrous sulphate solution dropwise in amount just sufficient to dissolve the precipitate and to leave a clear solution.

Cool the solution, and transfer to a 250-ml. graduated flask, make up to the mark, mix, and pipette two 20-ml. portions into clean dry beakers *A* and *B*.

To *A*, add 10 ml. of 10% ammonium molybdate, mix and allow to stand for 15 min. at 20° C. ± 3° C. Add 20 ml. of 10% oxalic acid and 5 ml. of 2% ferrous sulphate.

To *B*, add 20 ml. of 10% oxalic acid, 10 ml. of 10% ammonium molybdate, and 5 ml. of 2% ferrous sulphate.

The difference in absorption between *A* and *B* at 6500 Å. is measured by an absorptiometer or spectrophotometer. The amount of silicon is determined by reference to a standard graph, prepared by adding known amounts of silicon to pure iron and carrying out the above procedure.

SULPHUR

Principle

A large weight of sample is dissolved in acid, most of the iron is separated with ether, and the sulphur is determined by precipitating barium sulphate.

Method

Dissolve a 25-g. sample in hydrochloric and nitric acids. Remove the nitric acid by several evaporations with HCl, and carry out an ether separation in the usual way. Evaporate the aqueous layer to a volume of 2–3 ml., dilute with water, and filter. Precipitate the sulphate in the filtrate with barium chloride, in a volume of 100 ml., and allow to stand for several hours before filtration.

PHOSPHORUS

Principle

Phosphorus Content > 0·002%—Phosphorus is precipitated as phosphomolybdate and determined volumetrically.

Phosphorus Content < 0·003%—Phosphorus is determined colorimetrically by the formation of a vanado-phosphomolybdate, followed by extraction of the yellow colour with organic solvents.[10]

Method

Dissolve a 1-g. sample in 30 ml. of nitric acid (1 : 2), drive off the nitrous fumes, add 10 ml. of freshly prepared 15% ammonium persulphate solution, and boil the solution for 5 min. Add 10 ml. of ammonium vanadate solution (2·5 g. of NH_4VO_3 in 500 ml. of water + 30 ml. of nitric acid, made up to 1 litre with

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water). Add 40 ml. of 5% ammonium molybdate and cool. Transfer to a separating funnel, and extract three times with small volumes of mixed solvent (amyl alcohol : amyl acetate, 2 : 1). Combine the organic layers and measure the yellow colour on a spectrophotometer or absorptiometer. Prepare a standard graph by adding known amounts of phosphorus to portions of pure iron, and carrying out the same procedure.

MANGANESE

Principle

Manganese is determined by the bismuthate method using a 10-g. sample, after most of the iron has been separated by ether.

Method

Dissolve a 10-g. sample in acid and separate the iron with ether. Evaporate the resulting aqueous layer with 1–2 ml. of sulphuric acid to remove all traces of chloride. Determine manganese by bismuthate.

NICKEL

Principle

Iron is removed by an ether separation, followed by dimethylglyoxime precipitation of nickel. The latter is finally determined colorimetrically by the iodine-dimethylglyoxime reaction.

Method

Dissolve a 10-g. sample in acid, and carry out an ether separation of iron. Precipitate nickel with dimethylglyoxime in alkaline tartrate solution. Filter, dissolve the precipitate in HCl, and evaporate the solution with a small amount of sulphuric acid, destroying organic matter by oxidation with nitric acid. Determine the nickel colorimetrically by the following procedure : To the weakly acid solution, add 10 ml. of 50% ammonium citrate, 5 ml. of 0·1 *N* iodine, 20 ml. of 1 : 1 ammonium hydroxide, and 5 ml. of dimethylglyoxime (5% in alcohol). Allow to stand for 15 min., and measure the orange-red colour by an absorptiometer or spectrophotometer.

COPPER

Principle

Copper is separated by precipitation with H_2S and finally determined colorimetrically by its reaction with sodium diethyldithiocarbamate.

Method

Dissolve a 10-g. sample in dilute sulphuric acid. Precipitate copper with H_2S, filter, ignite the precipitate and dissolve in a small amount of nitric acid. Determine copper by reaction with sodium diethyldithiocarbamate, in the presence of citrate, and measure the golden-brown colour by an absorptiometer or spectrophotometer.

CHROMIUM

Principle

Most of the iron is removed by an ether separation. In the resulting solution, chromium is oxidized with potassium bromate, and determined colorimetrically by reaction with diphenylcarbazide.[11]

Method

Dissolve a 10-g. sample in acid, and separate most of the iron with ether. Evaporate the aqueous layer with 20 ml. of Spekker acid (15% of H_3PO_4 + 15% of H_2SO_4 v/v) to fumes, and dilute to 60 ml. with water. Add 10 ml. of 0·05% manganous sulphate and 10 ml. of 3% potassium bromate solution, and boil for 5 min. Add 10 ml. of 5% ammonium sulphate solution and boil for 10 min., cool, and dilute to 100 ml. with water. Determine chromium in a suitable aliquot of this solution by adding 25 ml. of 4% phosphoric acid and 5 ml. of 0·25% diphenylcarbazide in acetone. Measure the reddish-violet colour by an absorptiometer.

ALUMINIUM

Principle

Iron is removed by an ether separation, followed by extraction of the iron–cupferron complex with chloroform at *p*H 0·5. Aluminium is determined in the filtrate by reaction with 'aluminon,' the ammonium salt of aurintricarboxylic acid.[12]

Method

Dissolve a 10-g. sample in acid, and carry out an ether separation of iron. Evaporate the aqueous layer, and repeat the ether separation to reduce the amount of iron to a minimum. Add 3 g. of ammonium chloride, and adjust the *p*H of the solution to 0·3, using a glass electrode. Add cupferron solution, allow to stand for 5 min., and extract with chloroform until the extract is colourless. Warm the aqueous layer to remove chloroform. Make up the volume to 50 ml., and take a suitable aliquot (usually 10 or 20 ml.). Add 5 ml. of 5*N* ammonium acetate, adjust the *p*H to 4·9–5·0 (using a glass electrode), and add 5 ml. of 0·2% 'aluminon' solution. Allow to stand for 15 min., and measure the red colour by an absorptiometer or spectrophotometer. Carry out a blank test on all reagents and procedures. Beryllium, if present, interferes.

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The Hot-Tearing of Steel

By J. M. Middleton, Assoc. Met., and H. T. Protheroe, Ph.D.

SYNOPSIS

An apparatus is described for determining the loads a steel will withstand before tearing at high temperatures. The effect of casting temperature, and the influence of composition (for the usual range of concentrations of C, Si, Mn, S, Ni, Cr, Cu, P, Mo, Ti, and V) upon the resistance to tearing, have been investigated. It is shown that hot-tearing is more likely to occur and is more severe at high casting temperatures than at low temperatures. Of the elements investigated, sulphur is the most deleterious, even small additions resulting in a lowering of the resistance to tearing. The most beneficial elements are Ti and V.

The mechanism of tearing and the effect of variations in hindrance to contraction are discussed.

Steels with various sulphur contents were deoxidized with different amounts of aluminium. The results indicate that aluminium has a beneficial effect only if the amounts are sufficient to ensure freedom from grain-boundary inclusions. Larger additions of aluminium result in further improvement, as a result of the alloying effect of this element.

Results of an investigation into the tear-resisting properties of killed and semi-killed steels, as normally used for ingot production, are given. The trends with respect to C, S, and Si are the same as when the steels are deoxidized according to accepted foundry practice.

Section I—THE MECHANISM OF TEARING, AND THE INFLUENCE OF COMPOSITION, CASTING TEMPERATURE, AND HINDRANCE TO CONTRACTION

THE introduction of radiographic and supersonic testing of steel castings has revealed defects which previously would have been undetected. Practical steps have been taken to reduce the tearing of steel in the course of its solidification and cooling in the mould, and the quality of castings has thus been improved.

The actual instant at which tearing occurs, during the cooling of any but a very simple casting, is almost impossible to determine, and depends on a number of factors such as hindrance to contraction, uniformity in direction of contraction, and the strength of the steel at any particular temperature. Previous investigators[1] have suggested a temperature range in which tearing is most likely to occur, but the actual tearing temperatures for particular steel compositions have not been determined. A review of most of the previous research has been prepared by one of the present authors.[2]

The object of this part of the research was to determine actual tearing temperatures for specific steels, and to obtain an indication of the effect of factors such as casting temperature, alloying elements, resistance to contraction, and so on. Complications due to non-uniformity in direction of contraction (which is bound to occur in castings of complicated design) have been eliminated by employing a straight bar of round section. The recorded breaking loads therefore apply only to this particular simple casting. They are the loads withstood before tearing occurred, under the conditions of the test, and are not finite strengths of the steels at the temperatures indicated.

EXPERIMENTAL AND MELTING PROCEDURE

The test bar is 24 in. long × 1·128 in. dia., with a cross-sectional area of 1 sq. in., and is moulded in a specially designed moulding box (Fig. 1). The bottom half of the box is constructed with a stepped-up portion at one end, to centralize the plate and spring and to ensure absolute rigidity when the bar contracts. The top half of the box is made to fit into the recess and rest against the stepped-up portion. A machined steel plate is screwed on to the end of the bottom box, and contains three pairs of grooves spaced to give spans of 6 in., 8 in., and 10 in. The grooves act as seatings for hardened steel rollers, which act as fulcra for the flat spring. In the centre of the machined plate is a hollow flanged plunger, which registers the movement of the bar on a dial gauge.

After moulding, two heat-resisting steel bolts are inserted, one at either end. The bolt of the pouring end is rigidly secured to the moulding box, and the other is screwed into the plunger. The runner of the bar is placed to give a hot spot in a position 20 in. from the spring end of the bar. Resistance to contraction is provided by one of a number of flat steel springs, 14 in. long × 3 in. wide, of thickness 0·185–0·37 in., depending on the amount of resistance required. The plate, fulcra, and spring were assembled on a tensile-testing machine, and the deflection was measured for various loads. Calibration details are given in Table I.

To maintain constant, for all experiments, the resistance to contraction offered by the sand, a standard moulding mixture was used, consisting of Arnolds' 26*A* silica sand bonded with 3·0% of bentonite and 2·0–3·0% of moisture. The moulds were cast at an equal time interval after moulding, to avoid variation in sand conditions as a result of drying out, etc. The steel was melted in a high-frequency furnace, and melting conditions were kept as constant as possible.

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The analysis of the basic composition was maintained by adopting the following melting procedure:

The base charge, boiler plate scrap of composition 0·18% of C, 0·35% of Mn, 0·07% of Si, 0·035% of S, and 0·032% of P, was charged into the furnace, and the power input was controlled at about 12–15 kW. Additions of varying amounts of white iron, to adjust carbon content, were made at equal time intervals after switching on, so that carbon losses were approximately uniform for each melt. The melting time for each charge (to attain maximum temperature) was kept constant. It was found possible to gauge the approximate time for the charge to drop to the required casting temperature. The ferro-manganese and ferro-silicon for deoxidation were added, in this order, approximately 3 min. before pouring, and a final addition of aluminium (equivalent to 1½ lb. per ton of steel) immediately before pouring. The desired composition of the standard charge was 0·21% of C, 0·85% of Mn, 0·35% of Si, 0·035% of S, and 0·035% of P. This procedure was adopted for all melts, and the final compositions were remarkably consistent. Variations in composition with respect to one element only were obtained by adding this element, when procurable, as the pure metal.

Every melt was analysed. The carbon content (except when intentionally altered) was found to be between 0·20 and 0·23%. Sulphur and phosphorus contents remained constant, being the same in the final melt as in the base charge. Manganese content was sometimes 0·80%, but was mainly in the range 0·84–0·87%. The silicon content varied between 0·34 and 0·37%.

Owing to the small capacity of the furnace, a separate melt was necessary for each test. Each composition investigated required at least six melts. If the C, Mn, S, and P contents did not vary more than the above values, the average composition for each series was considered that of the standard charge.

Casting temperatures were determined with a Pt/Pt–13%Rh thermocouple. A bare thermocouple was inserted in the mould at the position of tearing, and temperature and contraction readings were taken at 5-sec. intervals until the temperature had fallen to 1200° C. Preliminary experiments had indicated that tearing always occurs above this temperature and within 3–4 min. after casting the bar. Initially, the runner was of the same diameter as the bar, which resulted in a considerable amount of porosity in the bar. After some tests to determine the correct shape and size of runner, the design finally adopted was 1·875 in. dia. tapering to 1·25 in. dia., the taper commencing 0·75 in. above the test bar; this was sufficient to provide adequate feeding. Figure 10 shows the section of an untorn bar and a torn bar when using this runner.

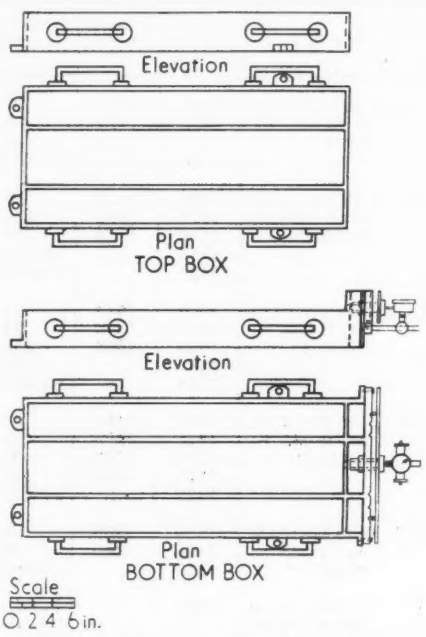

Fig. 1—Diagram of moulding box

Table I

LOAD-DEFLECTION CALIBRATION OF SPRINGS

Spring	Thickness, in.	Load per 0·001-in. Deflection, lb.	
		6-in. Span	8-in. Span
E	0·185	10	4·7
F	0·233	17	9·0
G	0·267	31	13·1
H	0·295	41	16·5
I	0·312	47	...
J	0·340	59	...
K	0·370	78	...

The *E* spring at 6-in. span offered sufficient resistance to contraction to cause tearing in most instances, and at the same time gave an easily readable deflection. A stronger spring caused tearing at higher temperatures and with lower loads. The test is therefore less sensitive when a strong spring is used.

DETERMINATION OF TEMPERATURE GRADIENTS IN THE BAR

The recorded temperatures are those of the skin at the position of tearing. The thermocouple for determining this temperature was placed in the side of the mould directly under the junction of the runner and bar. This is the hottest, and therefore the weakest, position at any time after casting, so that tearing always occurs here.

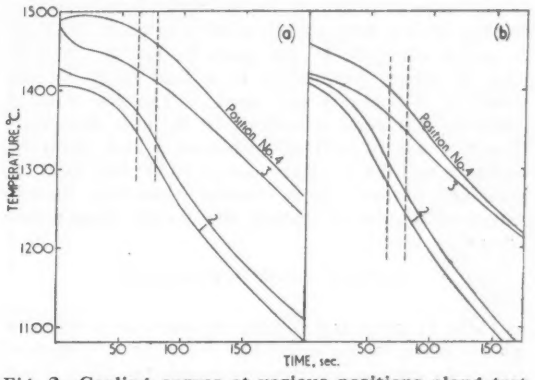

Fig. 2—Cooling curves at various positions along test bar cast at (*a*) 1600° C.; (*b*) 1525° C.

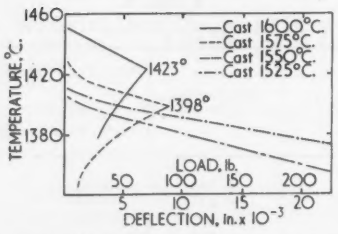

Fig. 3—Temperature/deflection curves for 0·21% C steel, using the *E* spring at 6-in. span

Temperature gradients were determined, for casting temperatures of 1600° and 1525° C., with thermocouples in the following positions:

Thermocouple No. 1: 3 in. from the spring end of the bar
No. 2: In the centre of the bar
No. 3: At the junction of bar and runner
(These were bare couples protruding approx. ¼ in. into the mould, and therefore recording skin temperatures)
No. 4: Lightly sheathed, protruding into the centre of the mould cavity at the junction of bar and runner.

The cooling curves shown in Fig. 2*a*, for a casting temperature of 1600° C., indicate the considerable temperature gradients existing in the skin of the bar. At the time of the first reading, the temperature at the end of the bar most remote from the runner is about 67° C. below that at the junction, and the temperature difference 200 sec. after casting is about 150° C. The temperature difference across the section at the junction is approximately 50° C.

Cooling curves for a casting temperature of 1525° C. are shown in Fig. 2*b*. About 65 sec. after casting, the temperature differences along the length of the bar are greater when cast at 1600° C. than when cast at 1525° C. Also, the temperature gradient across the section at the position of tearing is somewhat greater with the higher casting temperature.

In these casts, tearing occurred 65–80 sec. after pouring; this range is indicated by the vertical dotted lines in Fig. 2.

THE EFFECT OF CASTING TEMPERATURE

The results obtained on a steel of composition 0·21% of C, 0·80% of Mn, 0·35% of Si, 0·035% of S, and 0·035% of P, are given in Fig. 3. A 6-in. span *E* spring (equivalent to a load of 10 lb. per 0·001-in. deflection) was used. The bar cast at 1600° C. withstood a load of 70 lb. and then tore. The bar cast at 1575° C. withstood a load of 90 lb., and tore at 1398° C. Bars cast at 1550° and 1525° C. remained untorn. It is evident, therefore, that to minimize the risk of tearing, the casting temperature should be low.

EFFECT OF COMPOSITION

Carbon

Table II gives the results obtained on a series of plain carbon steels, using the *E* spring at a span of 6 in. As the carbon content exceeded 0·31%, it was found increasingly difficult to detect the point of fracture from the temperature/deflection curve; the difference in the solidification ranges of low-carbon and high-carbon steels may account for this. With lower carbon contents, steel solidifies over a small temperature range, and it can be assumed that the bar is completely solid when fracture occurs. With higher carbon steels, however, the temperature range is much wider, and a small amount of liquid remains in the interior when the solid skin is on the point of fracture. When tearing does occur, this liquid tends to re-weld the fracture, and the release of tension on the spring is never complete. On using the stronger spring *F*, the resistance to contraction was increased and the point of fracture became evident on the curve. The results for spring *F*, however, cannot be compared with those for spring *E*, because the stronger spring gives lower load figures and higher tearing temperatures.

Table II indicates that, for a given casting temperature, the resistance to contraction that a steel can withstand without tearing decreases with increase of carbon content.

The 0·07% C steel does not comply with this generalization, and for casting temperatures of 1600° and 1575° C. has a lower resistance to contraction than steels with higher carbon content. As the Mn content was lower than in the other steels, the experiments were repeated with Mn contents of 0·54 and 0·80%, but the results were almost identical. A possible explanation is offered by a consideration of the phase changes in such a steel. Figure 2*a* shows that, for a casting temperature of 1600° C., the temperature of the interior of the bar at the position of tearing is about 50° C. above the skin temperature. When tearing occurs the

Table II
RESULTS FOR PLAIN CARBON STEELS

Composition, %	Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·07 C 0·30 Mn; 0·22 Si; 0·035 S; 0·035 P	1600	1420	10
	1575	1413	10
	1565	1410	15
	1550	...	Unbroken
0·16 C 0·70 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1423	110
	1575	1398	120
	1550	1363	230
	1550	...	Slight tear
	1525	...	Unbroken
0·21 C 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1423	70
	1575	1398	90
	1565	1389	150
	1558	...	170
	1550	...	Unbroken
0·31 C 0·85 Mn; 0·31 Si; 0·035 S; 0·035 P	1600	1410	50
	1575	1400	80
	1550	1375	90
	1525	1365	135
	1525	...	Partly torn
0·40 C 0·80 Mn; 0·31 Si; 0·035 S; 0·035 P	1550	1385	30
	1525	1365	115
	1510	...	Unbroken
0·49 C 0·70 Mn; 0·30 Si; 0·035 S; 0·035 P	1510	...	Partly broken

temperature inside the bar is such that some of the δ-phase still exists, which suggests that steels when in this range have very low strength and/or ductility. When cast at lower temperatures, the whole section of the bar is below the $\delta + \gamma$ range before the stresses resulting from the contraction farther along the bar have become sufficiently powerful to exceed the strength of the steel.

In the remaining experiments on the effect of composition, the carbon content of the steel was fixed at 0·21%.

Sulphur, Phosphorus, Silicon, and Manganese

For all tests that resulted in an untorn or only very slightly torn bar, the load resisted is taken as more than 220 lb. This was the highest load recorded, and it was found that, for the *E* spring, fracture would not occur if the bar had already withstood such a load.

The results for a series of casts, of sulphur content 0·015–0·072%, are given in Table III. As the sulphur content increases, the resistance to contraction that the steel will withstand without tearing decreases. For a given sulphur content, however, greater contraction stresses are resisted with lower casting temperatures.

Table III shows that increasing the phosphorus content from 0·035 to 0·09% has very little effect at the higher casting temperatures, but results in a considerable drop in resistance to tearing for the lower casting temperatures. With an equal phosphorus content, however, the loads withstood are greater for lower than for higher casting temperatures.

In the amount normally encountered in steel, phosphorus does not affect the tear-resisting properties. Steels containing a certain amount of phosphorus resist greater contraction stresses than steels containing an equal amount of sulphur. Further evidence of the more deleterious effect of sulphur is given in

Table III

RESULTS FOR THE SULPHUR AND PHOSPHORUS SERIES

Composition, %		Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·015 S	0·22 C; 0·75 Mn; 0·31 Si; 0·035 P	1600	1390	180
		1575	...	Slight tear
		1550	...	Unbroken
0·035 S	0·21 C; 0·80 Mn; 0·35 Si; 0·035 P	1600	1423	70
		1575	1398	90
		1565	1389	150
		1550	...	Unbroken
0·055 S	0·21 C; 0·80 Mn; 0·35 Si; 0·035 P	1600	1428	5
		1575	1405	35
		1550	1387	60
		1535	...	Unbroken
0·072 S	0·21 C; 0·80 Mn; 0·35 Si; 0·035 P	1575	1408	20
		1550	1400	30
		1535	1389	65
		1525	...	Unbroken
0·035 P	0·21 C; 0·80 Mn; 0·35 Si; 0·035 S	1600	1423	70
		1575	1398	90
		1565	1389	150
		1550	...	Unbroken
0·09 P		1600	1410	60
		1575	1382	85
		1550	1373	90
		1535	1362	200
		1525	...	Unbroken
0·14 P		1600	1420	10
		1575	1388	70
		1550	1367	70
		1535	1361	85
		1525	...	Unbroken
0·20 P		1575	1392	25
		1550	1362	55
		1535	1361	65
		1525	...	Unbroken

Table IV

RESULTS FOR THE MANGANESE AND SILICON SERIES

Composition, %		Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·27 Mn	0·21 C; 0·35 Si; 0·035 S; 0·035 P	1600	1418	48
		1575	1401	55
		1550	1384	65
		1535	...	Unbroken
0·85 Mn		1600	1423	70
		1575	1398	90
		1565	1389	150
		1550	...	Unbroken
1·21 Mn		1600	1417	70
		1575	1408	95
		1565	1390	180
		1550	...	Slight tear
		1525	...	Unbroken
1·71 Mn		1600	1418	50
		1575	1404	55
		1550	1387	90
		1535	...	Unbroken
2·46 Mn		1600	1411	65
		1575	1404	65
		1565	...	Slight tear
		1550	...	Unbroken
0·05 Si	0·21 C; 0·85 Mn; 0·035 S; 0·035 P	1600	1412	50
		1575	1404	65
		1565	1393	125
		1550	...	Unbroken
0·35 Si		1600	1423	70
		1575	1398	90
		1565	1389	150
		1550	...	Unbroken
0·50 Si		1600	1412	50
		1575	1400	65
		1565	...	Slight tear
		1550	...	Unbroken
0·90 Si		1600	1415	40
		1575	1402	50
		1550	1387	90
		1535	1383	110
		1525	...	Unbroken

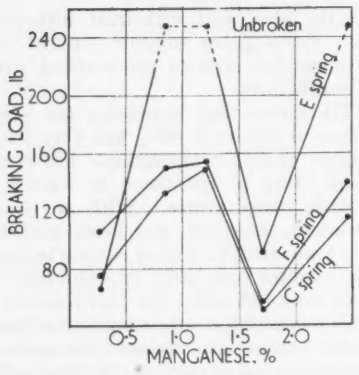

Fig. 4—Curves showing the effect of variations in hindrance-to-contraction, on manganese steels cast at 1550° C.

Table III, which shows that the steel containing 0·035% of S and 0·14% of P has a greater resistance to tearing than the steel containing 0·072% of S and 0·035% of P.

The effect of silicon is peculiar (*see* Table IV). With the lowest casting temperature (1550° C.) the addition of up to 0·5% of Si results in a steel that does not tear ; with 0·9% of Si, tearing occurs at a load of 90 lb. With casting temperatures of 1565°, 1575°, and 1600° C., the increase of Si content from 0·05 to 0·35% results in a slight improvement in all cases. A further increase of Si to 0·50% gives an improvement only with a casting temperature of 1565° C. With casting temperatures of 1575° and 1600° C. the 0·5% Si steel has practically the same tear-resisting properties as the original 0·05% Si steel. A logical explanation cannot be given. It is possible that, up to 0·35%, the deoxidizing effect of silicon enhances the hot-tearing results, and that above 0·35% the alloying effect of silicon has a more potent influence. In the manganese series (Table IV) the steel containing 0·27% of Mn has the lowest resistance to tearing, possibly owing to the low Mn/S ratio. An increase in manganese to 1·21% gives an improvement for all casting temperatures. Further increases up to 1·7% result in a decrease in properties, which is much more definite with the lower casting temperature ; further increases up to 2·46% result in a slight improvement.

It is not known why steel containing 1·7% of Mn offers low resistance to contraction. The curves obtained when using stronger springs, *i.e.*, by increasing the hindrance to contraction, are given in Fig. 4, and show identical trends. The lower breaking loads for the stronger springs are to be expected (*see* p. 390).

Table V

RESULTS FOR THE CHROMIUM AND NICKEL SERIES

Composition, %		Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·93 Cr		1600	1412	70
		1575	1400	80
		1550	1383	80
		1535	...	Unbroken
1·80 Cr	0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1409	50
		1575	1400	55
		1550	1392	85
		1535	...	Unbroken
2·55 Cr		1600	1402	145
		1575	1393	200
		1565	1392	195
		1550	...	Unbroken
1·0 Ni		1600	1411	45
		1575	1394	55
		1550	1384	65
		1535	1368	180
		1525	...	Unbroken
2·4 Ni		1600	1408	35
		1575	1389	35
		1550	1384	48
	0·21 C; 0·85 Mn ; 0·35 Si; 0·035 S; 0·035 P	1535	1383	65
		1525	...	Slight tear
3·65 Ni		1575	1404	35
		1550	1384	58
		1535	1383	72
		1525	...	Partly broken
2·4 Ni, 0·93 Cr		1600	1403	50
		1575	1399	85
		1550	1386	95
		1535	1375	100
		1525	...	Slight tear

Nickel and Chromium

The effect of chromium is shown in Table V. With chromium contents of 0·93 and 1·8%, tear-resisting properties are very much lower with low casting temperatures but only slightly lower with the higher casting temperatures, compared with the 0·21% plain carbon steel. When the chromium content is increased to 2·55%, tear-resisting properties exceeding those of the plain carbon steel are obtained.

The effect of nickel (Table V) up to 2·4% is to reduce the resistance to tearing, for all casting temperatures. With further additions up to 3·56%,

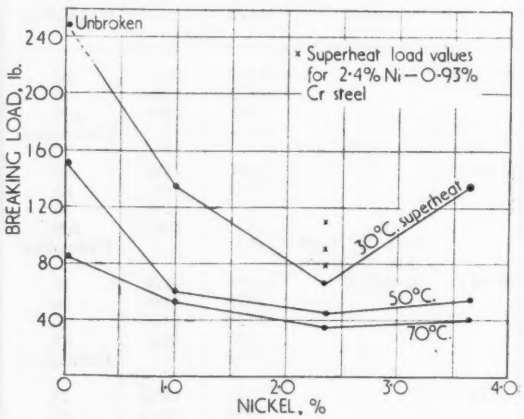

Fig. 5—The effect of nickel on the maximum loads withstood before tearing, for various degrees of superheat. (*E* spring)

no further reduction in properties is evidenced, and for the two lower casting temperatures there is a slight improvement.

It has been demonstrated that high casting temperatures have an adverse effect, and as the casting temperatures for plain carbon steels are too high for nickel steels, any comparison of tearing characteristics based on casting temperatures should take this into account. The curves shown in Fig. 5 are based on the degree of superheat, *i.e.*, the number of degrees by which the casting temperature exceeds the liquidus. The liquidus temperature for each composition has been obtained from the work of Andrew and Binnie,[3] who state that the percentage of nickel, or combined

Table VI

RESULTS FOR THE COPPER, MOLYBDENUM, TITANIUM, AND VANADIUM SERIES

Composition, %	Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
1·20 Cu; 0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1410	85
	1575	1394	110
	1550	1373	220
	1535	1361	220
	1525	...	Unbroken
3·0 Cu; 0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1407	85
	1575	1387	120
	1550	1379	110
	1525	1377	120
0·30 Mo; 0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1409	60
	1575	1401	90
	1550	1387	100
	1535	...	Unbroken
0·55 Mo; 0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1423	70
	1575	1404	90
	1550	1384	110
	1535	...	Slight tear
	1525	...	Unbroken
0·95 Mo; 0·21 C; 0·85 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1412	90
	1575	1398	85
	1565	...	Unbroken
	1550	...	Unbroken
0·07 Ti; 0·45 Si; 0·21 C; 0·85 Mn; 0·035 S; 0·035 P	1600	1412	70
	1575	1399	80
	1550	1379	120
	1535	...	Unbroken
0·25 Ti; 0·70 Si; 0·21 C; 0·85 Mn; 0·035 S; 0·035 P	1600	1412	90
	1575	1398	125
	1565	1371	205
	1550	...	Unbroken
0·37 V; 0·21 C; 0·80 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1417	90
	1575	1398	90
	1550	1378	170
	1535	...	Unbroken
1·16 V; 0·21 C; 0·80 Mn; 0·35 Si; 0·035 S; 0·035 P	1600	1390	165
	1575	...	Partly broken
	1550	...	Slight tear
	1535	...	Unbroken

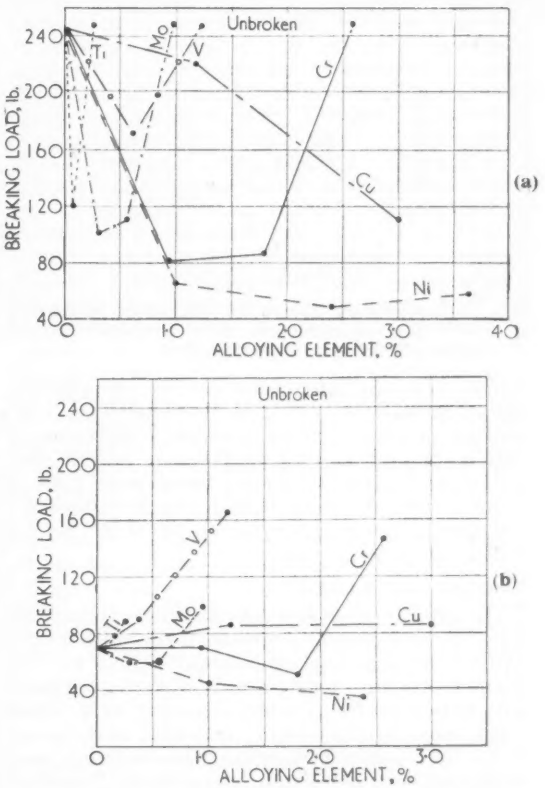

Fig. 6—Curves showing the effect of alloying elements (*E* spring). (*a*) Cast at 1550° C.; (*b*) cast at 1600° C.

percentage of nickel and chromium, multiplied by 4·8 gives the approximate lowering of the liquidus in degrees Celsius. Figure 5 shows that the load withstood by the test is much lower with the nickel steels than with plain carbon steels, for the same degree of superheat.

Table V contains also the results of tests on a 2·4%Ni–0·93%Cr steel; the superheat load values are indicated in Fig. 5. The Ni–Cr steel has better tear-resisting properties than the plain nickel steel.

Copper

The results obtained with 1·2 and 3·0% of Cu are given in Table VI. With casting temperatures lower than 1535° C. the tear-resisting properties are reduced, but with the higher casting temperatures there is a slight improvement. When considered from the point of view of superheat, there is a big difference with the 1·2% Cu steel; with 3% of Cu, however, the difference does not appear to be so critical, as there is not such a great difference in loads resisted for any casting temperature. This suggests that the 3% Cu steel has fairly good strength at high temperatures, but gains strength slowly with fall in temperature.

Molybdenum

Results for the three Mo steels are given in Table VI. With 0·30% of Mo, the tearing strength drops to 100 lb., compared with more than 220 lb. for the plain

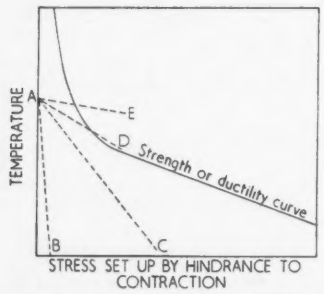

Fig. 7—Explanatory curves for variations in tearing loads and temperatures with alteration to the degree of hindrance to contraction

carbon steel, with the lowest casting temperature; but an increase to 0·95% of Mo restores the tear-resisting properties. With a casting temperature of 1575° C. the influence of molybdenum is negligible, and with the 1600° C. casting temperature there is an initial drop in tearing strength from 70 lb. to 60 lb., and then a gradual increase up to 90 lb. for the 0·95% Mo steel.

Titanium and Vanadium

The effect of these elements is also shown in Table VI. The only drop in properties occurs with 0·07% Ti steel, for a casting temperature of 1575° C. The titanium-free steel resists a load of 90 lb., compared with 80 lb. for 0·07% Ti steel—a drop of 10 lb., which is equivalent to only 0·001 in. deflection on the gauge. It can be considered, therefore, that even very small additions of titanium give an improvement. Vanadium also is beneficial. For all compositions, the tear-resisting properties exceed those of the plain carbon steel.

The comparative effects of the various alloying elements can be more readily obtained from Figs. 6*a* and *b*, which are typical graphs of tearing strength *versus* composition, for casting temperatures of 1550° and 1600° C.

MICRO-EXAMINATION

A systematic micro-examination of all the casts was made, to provide an indication of the cleanliness of the steel and the distribution of the inclusions. The effect of inclusions on hot-tearing has received some attention,[4] particularly in regard to their distribution. In all the plain carbon steels, and in those to which the usual alloying elements Ni, Cr, Cu, etc., had been added, inclusions were few and were of random distribution. A typical example is shown in Fig. 11*a*.

The steels with varying sulphur content, however, revealed that those with the higher sulphur content contained a considerable amount of the intergranular type of inclusion. Figures 11*b* and *c* show the distribution of the inclusions in the 0·055% and 0·072% S steels. These intergranular inclusions are present in all except the lowest sulphur steels, and become more general as the sulphur increases. With very high sulphur contents, they form almost complete networks around the grains. This probably accounts for the low resistance to tearing evident in the high-sulphur steels.

The presence and extent of intergranular inclusions resulting from the addition of sulphur largely depend on the amount of aluminium added to the steel. This subject is considered more fully in Section II.

THEORETICAL CONSIDERATIONS AND DISCUSSION

The cause of hot-tearing is known to be the hindrance to contraction after complete or partial solidification. The use of collapsible cores and the digging away of sand from around runners and risers is universally practised, to minimize the effect of such hindrance.

The contraction of steel proceeds down to room temperature, but this fact is not important when considering hot-tearing, as rupture occurs within a limited range of temperature. Only that portion of the contraction curve within this temperature range need be considered. The critical condition underlying the cause of fracture is the hindrance to free contraction of the casting by reason of its design. If a simple, straight bar is considered, contraction is unhindered and no stresses are set up, except perhaps as a result of the resistance to contraction offered by the friction of the sand. These, however, will be of very small magnitude, and the slope of the stress curve under such conditions will be as AB in Fig. 7. As the resistance to contraction is increased the stresses become greater and the slope of the line progressively decreases (lines AC and AD). If the rate of solidification is such that sufficient solid is formed, and if the hindrance to contraction permits, it is possible to have an almost horizontal line, as AE.

The few determinations that have been made[5, 6] of actual strengths at elevated temperatures have revealed that they are very low, and at temperatures near the solidus are practically zero. Gain in strength with falling temperature is coincident with gain in ductility, but the predominance of one over the other depends on the composition of the steel. If a strength or ductility curve is superposed (*see* Fig. 7), stresses due to contraction will, in some cases, exceed the strength or ductility of the steel, and tearing will result. If, therefore, the steel has sufficient strength to cause deformation of the sand or cores in a mould, or to accommodate the stresses caused by any other form of hindrance to contraction, it will not tear even if the ductility is low. Also, if the steel has sufficient ductility to flow plastically, it will not tear even if its strength is low. The hindrance to contraction must be considered in conjunction with strength and ductility.

The reason why lower tearing loads and high tearing temperatures were obtained when using a stronger spring, in the carbon and manganese series, is evident from Fig. 7. The slope of the stress line decreases because of the greater hindrance to contraction, and the line cuts the strength curve at a point higher up on the temperature axis.

The recorded tearing loads cannot be taken as the finite strength of the steel at the particular tearing temperature, because the breaking loads of steel at elevated temperatures depend on the rate of straining.[7] These experimental results, therefore, indicate the maximum load a steel of any composition will withstand under the conditions of test. Alteration to the

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size of the bar, location of runner, and hindrance to contraction, etc., will alter the load figures. However, the test does give a comparison of the tearing propensities of steels of different compositions under identical conditions.

The temperature of tearing for a given composition is determined by the rate of gain in strength compared with the rate of stress development. The former is dependent only on the rate of cooling, but the rate of stress development is determined by the variation in contraction along the length of the bar. Considerable longitudinal temperature gradients have been shown to exist. In such circumstances, one portion of the bar undergoes considerable contraction before the steel in the hottest zone has developed its strength. Tearing will always occur, therefore, at the hottest spot, which, in this case is at the junction of the bar and runner. This point is well realized, as evidenced by attempts in practice to equalize the rate of cooling by the use of chills, attention to casting design, the judicious positioning of runners, and so on.

Experiments have shown that hot-tearing is more likely to occur, and is more severe, with high casting temperature. The explanation for this is not so simple as might at first appear, because casting temperature does not affect the amount of solid contraction. It does, however, affect the rate of solidification, but the circumstances that control contraction similarly control stress formation. The rate of stress formation increases or decreases with the rate of strength development.

Thus, if the strength characteristics are such that the steel tears readily, it should tear regardless of the time taken to cool to this tearing temperature; similarly, if the strength characteristics ensure freedom from tearing for one solidification rate, they should ensure it for another. Theoretically, therefore, casting temperature should affect tearing only in respect of time. This, however, only applies if solidification is uniform and if the *whole* of the casting is at the same temperature at any time after casting.

Temperature gradients have been shown (Fig. 2) to exist both longitudinally and across the section of the bar. Tearing, therefore, depends on the relative amounts of comparatively strong (cool) steel and comparatively weak (hot) steel. Low casting temperatures favour a more uniform solidification rate throughout the bar, so that strength development is also more uniform. With higher casting temperatures the temperature gradients are steeper, and some portion of the bar might have undergone considerable contraction, another portion being hot enough to be very weak.

A low casting temperature ensures the rapid formation of an appreciable solid skin, immediately on casting. Figures 12*a* and *b* show the macro-etched section of a steel cast at 1525° and 1600° C., respectively; the depth of chill crystals is greater for the lower casting temperature. The equi-axed structure of the whole section in Fig. 12*a* (*cf.* the dendritic structure in Fig. 12*b*) indicates the influence of a flatter temperature gradient.

Section II—THE EFFECT OF DEOXIDATION WITH ALUMINIUM

So far as the authors are aware, the only published literature on the influence exerted by the products of deoxidation on the susceptibility of steel to hot-tearing is that by Craft and co-workers[4] and by Phillips.[8] Although Craft made only a limited study of hot-tearing, both investigations justified the authors' conclusion that the more completely the steel is deoxidized, the less is its susceptibility to tearing.

Other investigators[4, 9–11] have concluded that the nature and distribution of the sulphide inclusions in cast steel are related to the degree of deoxidation. It has been shown that when a steel is deoxidized with aluminium there is a critical amount of this element which results in minimum ductility : it is that required to effect complete deoxidation without leaving an appreciable excess in the steel. In such circumstances the sulphides are precipitated in the grain boundaries, and this results in low ductility. Experimental results have confirmed that the intergranular inclusions have a similar deleterious effect on the strength of the steel at elevated temperatures, and so influence the susceptibility to tearing.

EXPERIMENTAL PROCEDURE

Melting was carried out in a 15-lb. capacity H.F. furnace. The ferro-manganese and ferro-silicon were added a few minutes before pouring, as in the previous experiments (*see* p. 385). Immediately before pouring, aluminium was added in the form of $\frac{1}{8}$-in. dia. wire, a predetermined length being dipped into the metal. The deoxidation effect of aluminium is more effective when used in this way than by simply throwing aluminium into the melt.

The effect of deoxidizing with aluminium was determined on steels of varying sulphur contents, since the sulphur content of a steel determines the amount of sulphide inclusions present. The aluminium additions varied from 0 to 0·10% for each sulphur level, the steel being first deoxidized with ferro-manganese and ferro-silicon as above. The charge

Table VII

ANALYSES OF SULPHUR STEELS

Steel	C, %	S, %	Si, %	Mn, %	P, %
0·022% S	0·21–0·23	0·020–0·023	0·30–0·35	0·75–0·80	0·035
0·042% S	0·21–0·23	0·041–0·043	0·35–0·40	0·70–0·80	0·025
0·066% S	0·20–0·23	0·065–0·067	0·30–0·40	0·65–0·70	0·027

Table VIII

RESULTS FOR STEELS DEOXIDIZED WITH SILICON AND ALUMINIUM

Deoxidation	Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·022% S Steel			
Si alone	1600	1422	80
	1600	1422	95
	1575	1416	110
	1575	1412	135
	1550	...	Unbroken
0·025% of Al	1600	1422	120
	1600	1416	110
	1575	...	Slight tear
	1550	...	Unbroken
0·05% of Al	1600	1412	130
	1600	1402	160
	1575	...	Slight tear
	1550	...	Unbroken
0·075% of Al	1600	1390	195
	1600	1390	180
	1575	...	Unbroken
0·10% of Al	1600	1395	200
	1600	...	Slight tear
	1575	...	Slight tear
	1550	...	Unbroken
0·042% S Steel			
Si alone	1600	1410	70
	1600	1410	70
	1575	1395	80
	1575	1390	95
	1550	1379	100
	1550	1370	122
0·025% of Al	1600	1409	45
	1600	1405	60
	1575	1395	65
	1575	1395	70
	1550	1379	95
	1550	1379	70
0·05% of Al	1600	1411	70
	1600	1414	60
	1575	1390	60
	1575	1390	60
	1550	1383	70
	1550	1379	85
0·075% of Al	1600	1409	60
	1600	1411	70
	1575	1395	75
	1575	1390	80
	1550	1375	115
	1550	1380	95
0·10% of Al	1600	1405	75
	1600	1409	70
	1575	1390	90
	1575	1390	100
	1550	...	Unbroken
	1550	...	Unbroken
0·066% S Steel			
Si alone	1550	1386	45
	1550	1386	45
0·025% of Al	1550	1390	20
	1550	1390	20
0·05% of Al	1550	1385	60
	1550	1383	40
0·075% of Al	1550	1383	80
	1550	1379	80
0·10% of Al	1550	1383	80
	1550	1383	80

was calculated to give a final composition within the ranges shown in Table VII.

EXPERIMENTAL RESULTS

0·022% Sulphur Steel

The results obtained for this steel are given in Table VIII. The low-sulphur steel offers high resistance to contraction stresses, but steel deoxidized solely with silicon is more susceptible to tearing, this susceptibility progressively decreasing with increasing additions of aluminium. This applies to all casting temperatures high enough to induce tearing. For a casting temperature of 1550° C., all the steels were untorn.

0·042% Sulphur Steel

The results obtained, shown in Table VIII, differ from those obtained for the 0·022% S steel, in that additions of 0·025–0·05% of Al cause a drop in the tear-resisting properties of the steel; but further addition of Al, up to 0·10%, results in a recovery of these properties. Improved tear-resisting properties were obtained when the steel contained more than 0·1% of Al.

0·066% Sulphur Steel

Results for this steel are given in Table VIII. Curves for each of the three sulphur levels, for a casting temperature of 1550° C., are given in Fig. 8. The curve obtained with the 0·066% S steel has the same trend as the curve for the 0·042% S steel. Additions of aluminium up to 0·025% lower the tear-resisting properties, but there is a progressive increase in properties when the aluminium is increased to 0·10%. It is noticeable, however, that the higher the sulphur content of the steel, the lower is its resistance to tearing. This applies for any percentage of aluminium; *e.g.*, 0·022% S steels remain untorn when cast from 1550° C., whilst 0·066% S steels tear with low loads.

EFFECT OF LARGER ALUMINIUM ADDITIONS

The effect of adding greater amounts of aluminium was investigated using 0·042% S steel. Results are given in Table IX, in which the percentage of alu-

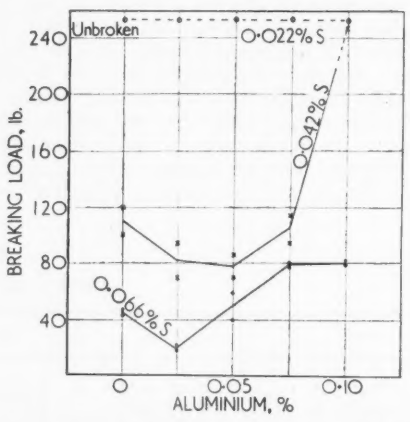

Fig. 8—The effect of aluminium on various sulphur steels cast at 1550° C.

minium is that of the residual, not added, aluminium.

Curves of tearing strength, for various casting temperatures, are shown in Fig. 9. The addition of 0·4–0·6% of Al markedly improved the steel's tear-resisting properties, especially when cast from the higher temperatures 1600° and 1575° C., but there was a slight drop in tear resistance with the 0·4% Al steel when cast from 1550° C.

When casting these higher-aluminium steels, it became apparent that the metal lacked fluidity and was enclosed by a very tenacious skin. A probable explanation of the higher resistance to contraction of these steels is that the skin develops strength rapidly with decreasing temperature, and is able to accommodate the contraction stresses. The high resistance offered to tearing when the steel contains higher percentages of deoxidizing elements such as Ti and V (*see* p. 390) is attributable to the true alloying effect of these elements, rather than to a deoxidation effect.

MICRO-EXAMINATION

A systematic micro-examination of all the test bars was undertaken, to determine the form and distribution of the inclusions.

Typical photomicrographs of the series of 0·022% S steels are shown in Fig. 13. The steels are reasonably clean and the inclusions are randomly distributed, no trace of inclusions being apparent around the crystal boundaries. The effect of increasing the aluminium additions has been to produce the irregularly shaped inclusions of alumina, or aluminate (Fig. 13*b*).

Typical photomicrographs of 0·042% S steels are shown in Fig. 14. The inclusions in the steel deoxidized with silicon alone take the form of rounded sulphides and silicates of random distribution (Fig. 14*a*). When additions of 0·025–0·05% of Al are made, the sulphides become intergranular, surrounding or partially surrounding the primary crystals. On increasing the aluminium addition to 0·075–0·10%, the intergranular inclusions are replaced by more-or-less randomly distributed angular inclusions (Fig. 14*b*).

Typical photomicrographs of 0·066% S steels are shown in Fig. 15. The series is similar to that of the 0·042% S steels in that an addition of 0·025% of Al has produced intergranular sulphide inclusions, although some of the inclusions are distributed as galaxies (Fig. 15*a*). Unlike the steel containing 0·042% of S, these grain-boundary sulphides have disappeared when more than 0·05% of Al has been added (Fig. 15*b*). The 0·066% S steel is much dirtier than the lower sulphur steels, and the sulphide inclusions are more massive. Figure 16 shows tearing associated with the grain-boundary inclusions in the steel deoxidized with 0·025% of Al.

Table IX

RESULTS FOR 0·042% S STEEL DEOXIDIZED WITH LARGER AMOUNTS OF ALUMINIUM

Composition, %	Casting Temp., °C.	Temp. of Tearing, °C.	Breaking Load, lb.
0·40 Al*	1600	1408	125
	1575	1386	125
0·23 C; 0·042 S; 0·35 Si; 0·75 Mn; 0·026 P	1550	1373	185
	1535	...	Unbroken
0·60 Al*	1600	1403	165
	1600	1403	160
	1575	...	Unbroken

* Residual aluminium

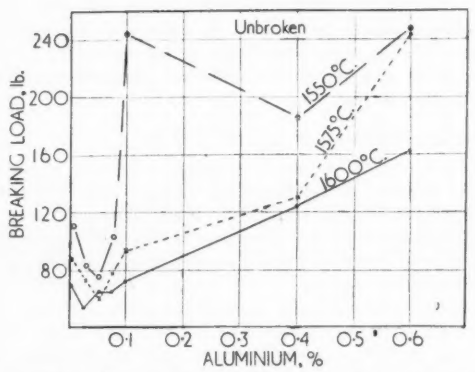

Fig. 9—The effect of large additions of aluminium on the 0·042% S steel, at various casting temperatures

DISCUSSION OF RESULTS

The resistance offered to tearing by the steel is influenced by its sulphur content and by the degree of deoxidation. A steel of low sulphur content is not so susceptible to tearing as one with a higher sulphur content, and, for a given sulphur, large additions of aluminium make the steel less susceptible to tearing.

In the range 0·042–0·066% S, small additions of 0·025–0·05% of Al to the silicon-killed steel lower the resistance to tearing in the same way as these additions lower the ductility at room temperatures. This reduction in tear-resisting properties probably results from the redistribution of the sulphide inclusions, which take the form of intergranular films, thereby acting as continuous lines of weakness and so lowering the strength and ductility of the steel at elevated temperatures. Sims[10] suggests that these intergranular films are formed as a result of the relative absence of FeO (due to aluminium additions). In the absence of oxygen, low-melting-point sulphides are formed, which precipitate late in the freezing of the steel and hence are finally located around the already solid steel crystals.

When the aluminium addition is increased to 0·075–0·10%, the intergranular sulphides are replaced by randomly distributed irregularly shaped inclusions. This change in the nature of the inclusions is accompanied by a recovery in tear-resisting properties. For any sulphur content, a steel to which 0·01% of Al has been added has a higher resistance to tearing than a similar steel deoxidized solely with silicon (*see* Fig. 8). This improvement is probably due to the changed nature of the inclusions, rather than to the alloying effect of such additions of aluminium. The amount of residual aluminium in the steel after an addition of 0·1% will be too small to have much effect on the high-temperature strength of the steel.

The affinity of aluminium for sulphur has been well established, although the actual composition of the product is still doubtful. Sims[10] states that aluminium and sulphur form a black compound, Al_2S_3. McCance[12] states that the product of the reaction is grey, while Craft[4] and co-workers suggest that the product is an aluminium oxysulphide.

It is certain that aluminium reacts with the FeS at high temperatures to produce an aluminium sulphide with a low solubility and a high melting point, giving rise to the randomly distributed inclusions.

Even in the presence of excess manganese, a steel will contain a fair proportion of sulphur as FeS at temperatures close to 1400° C. This has been established by Whiteley[13] and McCance.[14] It is only at a lower temperature that the reaction FeS + Mn = MnS + Fe proceeds to the right to any marked extent, and as the melting point (1193° C.) of FeS is considerably below the solidification temperature of steel, it remains liquid long enough to impair the strength of the steel.

The reason for the higher resistance to tearing of the low-sulphur steels, as compared with those of higher sulphur content, is that the relatively lesser amounts of sulphide do not weaken the steel to the same extent, and the chance of producing grain-boundary inclusions is considerably lessened.

Section III—THE HOT-TEARING SUSCEPTIBILITY OF A SERIES OF KILLED AND SEMI-KILLED STEELS

Little information has been published on the susceptibility to tearing of semi-killed steels, and the present work was therefore undertaken to compare the tear resistance of killed or semi-killed steels of varying carbon content, and to determine the effect that higher sulphur content has upon this property.

EXPERIMENTAL PROCEDURE

The experimental procedure was as described on p. 384. For all experiments, the steel was melted in a sillimanite crucible. The temperature from which a test bar is cast has considerable influence upon its propensity towards tearing (*see* p. 386). To keep casting conditions as constant as possible, the various carbon steels were therefore poured with equal degrees of superheat, in this case 50° C. Values for the liquidus temperatures of these steels were obtained from the work of Roeser and Wensel.[15]

Initial experiments were necessary to determine the lowest silicon content (without addition of aluminium) that would adequately deoxidize the steel and produce a sound test bar. It was found that, for carbon contents of 0·1 and 0·2%, a silicon content of 0·27% would give a sound bar, but with 0·4% of carbon the amount of silicon had to be increased to 0·32–0·34% to obtain a test bar free from blowholes.

Figure 17 shows sections, taken at the positions of tearing, of semi-killed and killed test bars containing 0·1% of C. Figure 17*a* is of a test bar to which a small amount (0·12%) of Si was added; the metal rose in the mould, and the section contains a large number of subcutaneous blowholes. Figure 17*b* is of a bar of similar composition to which an aluminium addition, of the order of 4 oz. per ton of steel, has been made. The effect of aluminium has been to lessen the quantity of blowholes. Figure 17*c* is of a fully killed steel containing 0·27% of Si; the metal sank in the mould and was perfectly free from blowholes. These three sections are also representative of the 0·2 and 0·4% C steel series.

In all the tests, the *E* spring at a 6-in. span was used to resist the contraction of the test bar. Results are given in Table X.

EXPERIMENTAL RESULTS

0·10–0·12% Carbon Steels

The results indicate that the steels had low resistance to tearing, which was only slightly affected by the degree of deoxidation. A reduction in the resistance to tearing was apparent when the sulphur content was raised from 0·02 to 0·059%.

0·20–0·23% Carbon Steel

The steels containing 0·2% of C and with low sulphur had a much greater resistance to tearing than similar steels with 0·1% of C, and for several test bars the spring employed in the test was insufficiently strong to cause complete rupture. The degree of deoxidation appeared to affect the tear-resisting properties of the lower-sulphur steels: the 0·12% Si steels had slightly lower resistance to tearing than the fully killed 0·27% Si steels.

Increasing the sulphur content from 0·022 to 0·059% greatly lowered the strength of the steel, regardless of the degree of deoxidation.

0·37–0·40% Carbon Steels

Low-sulphur steels containing 0·37–0·40% of C had lower resistance to tearing than similar steels with 0·2% of C, but showed higher resistance than steels with 0·1% of C.

The amount of silicon, *i.e.*, the degree of deoxidation, had little influence upon the tear-resisting properties of the steel, but increasing the sulphur content of the steel from 0·022 to 0·050% markedly lowered these properties.

MICRO-EXAMINATION

A systematic micro-examination of the test bars was undertaken, to give an indication of the cleanliness of the steel and the type and distribution of the inclusions present. Representative photomicrographs are shown in Fig. 18.

Low-Silicon Steels (0·12–0·19% of Si)

Steels of low Si and S content had few inclusions, those present being rounded silicates and sulphides of random distribution (Fig. 18*a*). The addition of Al (4 oz. per ton) to these steels did not change the nature of the inclusions, although the Al-killed steels were slightly dirtier.

Figure 18*b* shows a low-silicon steel without aluminium additions, containing 0·056% of S. The effect of the higher sulphur content was to increase the amount of sulphide inclusions, these sulphides being rounded and of random distribution. The addition

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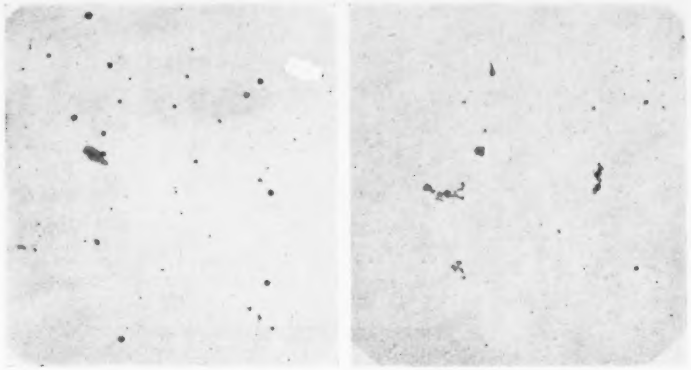
Fig. 10—Sections of test bars at position of tearing (using the 1·875-in. dia. runner) showing absence of porosity. (*a*) Untorn bar cast at 1525° C.; (*b*) torn bar cast at 1600° C.

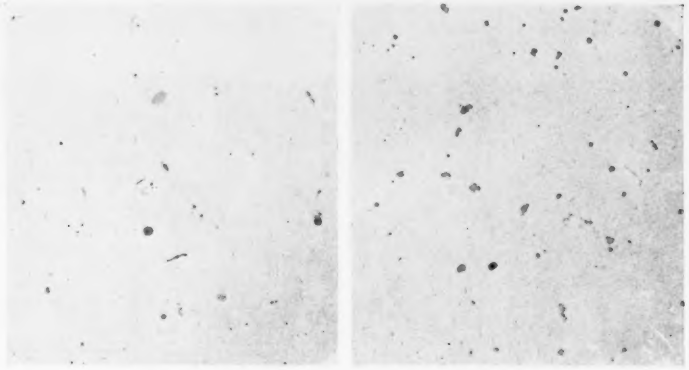
Fig. 11—Photomicrographs of inclusions × 200. (*a*) Typical randomly distributed inclusions; (*b*) intergranular inclusions in the 0·055% S steel; (*c*) intergranular inclusions in the 0·072% S steel

Fig. 12—Macro-etched sections of a steel cast at: (*a*) 1525° C.; (*b*) 1600° C. × 3



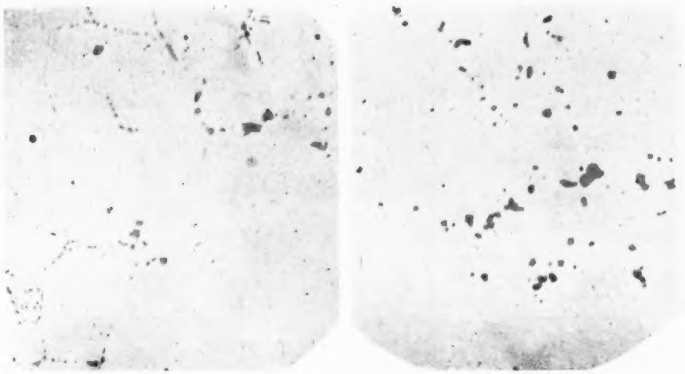
(a) (b)

Fig. 13—Randomly distributed inclusions in the 0·022% S steel × 200. (*a*) Deoxidized with Si ; (*b*) deoxidized with 0·10% of Al



(a) (b)

Fig. 14—Randomly distributed inclusions in the 0·042% S steel × 200. (*a*) Deoxidized with Si ; (*b*) deoxidized with 0·10% of Al



(a) (b)

Fig. 15—Inclusions in the 0·066% S steel × 200. (*a*) Deoxidized with 0·025% of Al, showing intergranular inclusions ; (*b*) deoxidized with 0·05% of Al, showing randomly distributed inclusions

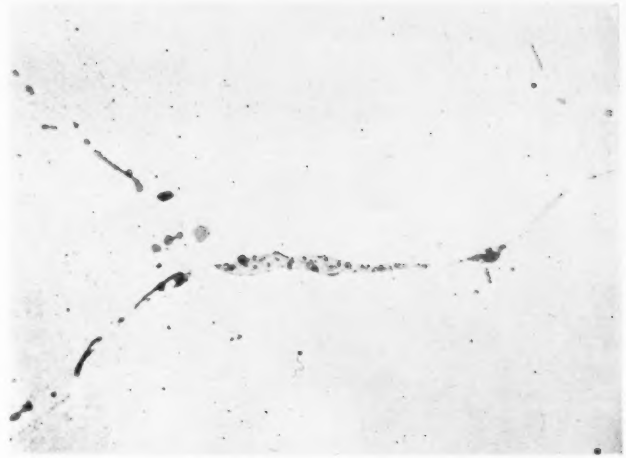
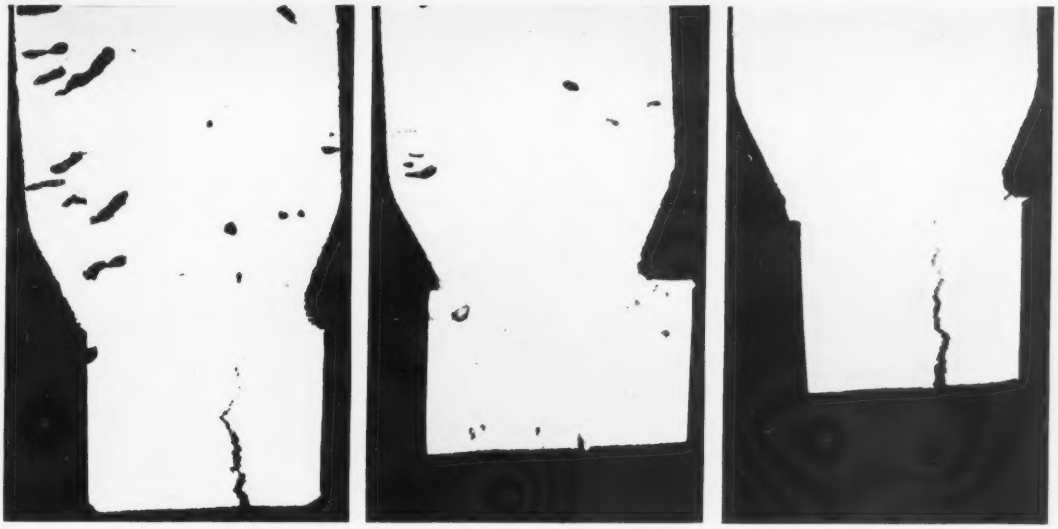
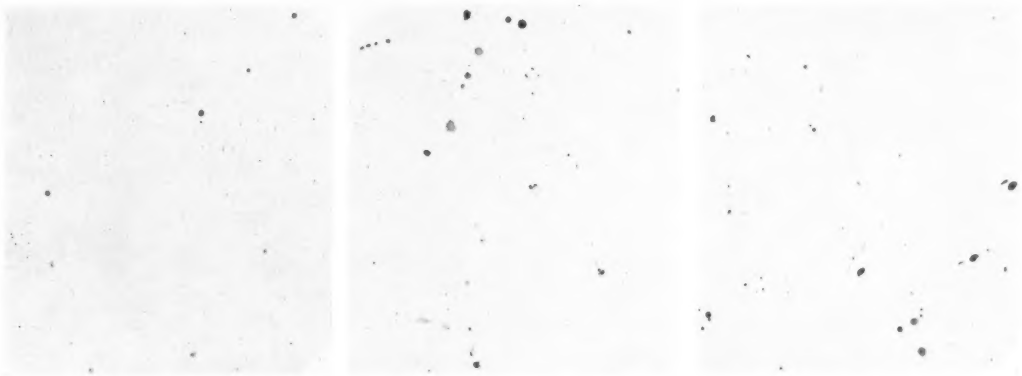


Fig. 16—Tearing associated with intergranular inclusions × 350



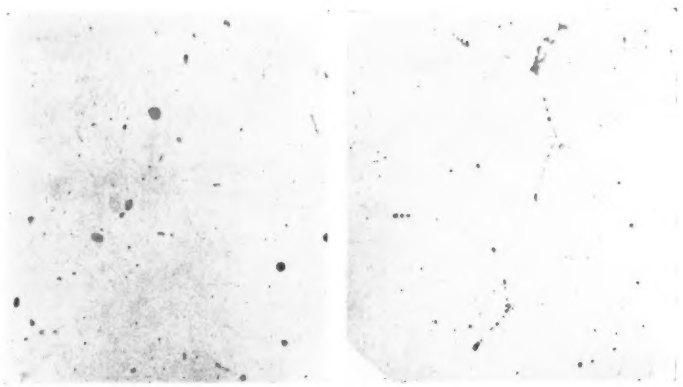
(a) (b) (c)

Fig. 17—Sections of killed and semi-killed test bars, at positions of tearing × 1 (*a*) Semi-killed, 0·12% of Si ; (*b*) semi-killed, 0·12% of Si and 4 oz. of Al per ton of steel ; (*c*) fully killed, 0·27% of Si



(a) (b) (c)

Fig. 18—Photomicrographs of inclusions present in low-silicon steels × 200. (*a*) Randomly distributed inclusions in 0·022% S steel deoxidized with Si ; (*b*) randomly distributed inclusions in 0·056% S steel deoxidized with Si ; (*c*) intergranular inclusions in 0·056% S steel deoxidized with Si and Al



(a) (b)

Randomly distributed Intergranular

Fig. 19—Photomicrographs of inclusions present in high-silicon 0·056% S steels × 200. (*a*) Deoxidized with Si ; (*b*) deoxidized with Si and Al

[*Middleton and Protheroe*

of small amounts (0·0125%) of Al caused more of the sulphides to be located around the primary grain boundaries (Fig. 18*c*). The amount was not sufficient to surround the grains as completely as in the sulphur steels deoxidized with 0·025–0·05% of Al (p. 392).

High-Silicon Steels (0·27–0·35% of Si)

The inclusion types and distributions in these steels are similar to those in the lower Si-content series (Fig. 18). Greater additions of Si resulted in an increase in the size of the silicate inclusions, and the effect of increasing the amount of sulphur from 0·022

Table X

RESULTS FOR SEMI-KILLED AND FULLY KILLED CARBON STEELS

Deoxidation	Cast No.	Composition, %					Temperature of Tearing, °C.	Breaking Load, lb.
		C	Si	S	Mn	P		
0·1% C Steels. Cast at 1576° C.								
0·12% of Si — Si	7	0·11	0·11	0·022	0·74	0·040	1420	40
0·12% of Si — Si	8	...	...	...	...	...	1409	55
0·12% of Si — Si + Al*	9	...	...	...	...	...	1413	37
0·12% of Si — Si + Al*	15	0·13	0·12	0·024	0·73	0·038	1413	45
		...	...	...	...	...		
0·12% of Si, higher S — Si	17	0·11	0·15	0·059	0·69	0·036	1420	25
0·12% of Si, higher S — Si	19	...	...	...	...	...	1420	27
0·12% of Si, higher S — Si + Al*	23	...	...	...	...	...	1413	27
0·27% of Si — Si	14	0·12	0·27	0·021	0·69	0·036	1409	45
0·27% of Si — Si	13	0·12	0·28	0·021	0·74	0·036	1413	60
0·27% of Si — Si + Al*	12	...	...	...	...	...	1417	50
0·27% of Si, higher S — Si	16	...	...	0·059	...	...	1409	35
0·27% of Si, higher S — Si	25	...	...	...	...	...	1412	32
0·27% of Si, higher S — Si + Al*	22	0·10	0·30	0·059	0·72	0·036	1409	35
0·27% of Si, higher S — Si + Al*	18	...	...	...	...	...	1410	20
0·2% C Steels. Cast at 1567° C.								
0·13% of Si — Si	34	0·20	0·13	0·020	0·56	0·040	1402	155
0·13% of Si — Si	42	...	...	...	...	...	1400	165
0·13% of Si — Si + Al*	35	...	...	...	...	...	1392	145
0·13% of Si — Si + Al*	41	...	...	...	...	...	1398	165
0·13% of Si; higher S — Si	37	0·19	0·14	0·057	0·67	0·040	1418	32
0·13% of Si; higher S — Si	36	...	...	...	...	...	1418	35
0·13% of Si; higher S — Si + Al*	38	0·20	0·14	0·056	0·70	0·037	1410	32
0·13% of Si; higher S — Si + Al*	39	0·20	...	...	...	...	1418	35
0·27% of Si — Si	26	0·23	0·27	0·016	0·74	0·034	1385	190
0·27% of Si — Si	30	...	...	...	...	...	Slight tear	
0·27% of Si — Si + Al*	29	0·24	0·26	0·022	0·74	0·038	Slight tear	
0·27% of Si — Si + Al*	31	...	...	...	...	...	Slight tear	
0·27% of Si; higher S — Si	27	0·23	0·29	0·057	0·80	0·031	1410	25
0·27% of Si; higher S — Si	32	...	...	...	...	...	1414	35
0·27% of Si; higher S — Si + Al*	28	0·23	0·28	0·055	0·84	0·034	1410	35
0·27% of Si; higher S — Si + Al*	33	...	...	...	...	...	1414	30
0·4% C Steels. Cast at 1558° C.								
0·19% of Si — Si	43	0·38	0·19	0·022	0·56	0·040	1396	90
0·19% of Si — Si	55	...	...	...	...	...	1401	85
0·19% of Si — Si + Al*	48	...	...	...	...	...	1385	90
0·19% of Si — Si + Al*	57	...	...	...	...	...	1391	90
0·19% of Si; higher S — Si	46	0·36	0·20	0·056	0·60	0·040	1396	45
0·19% of Si; higher S — Si	53	...	...	...	...	...	1401	20
0·19% of Si; higher S — Si + Al*	49	...	...	...	...	...	1396	25
0·19% of Si; higher S — Si + Al*	54	...	...	...	...	...	1407	30
0·32% of Si — Si	44	0·40	0·34	0·020	0·76	0·040	1396	90
0·32% of Si — Si	56	...	...	...	...	...	1391	90
0·32% of Si — Si + Al*	47	...	...	...	...	...	1391	95
0·32% of Si — Si + Al*	52	...	...	...	...	...	1385	115
0·32% of Si; higher S — Si	51	...	...	...	...	...	1396	30
0·32% of Si; higher S — Si	45	0·37	0·32	0·056	0·76	0·040	1396	35
0·32% of Si; higher S — Si + Al*	50	...	...	...	...	...	1396	25

* Aluminium addition: 4 oz. per ton of steel

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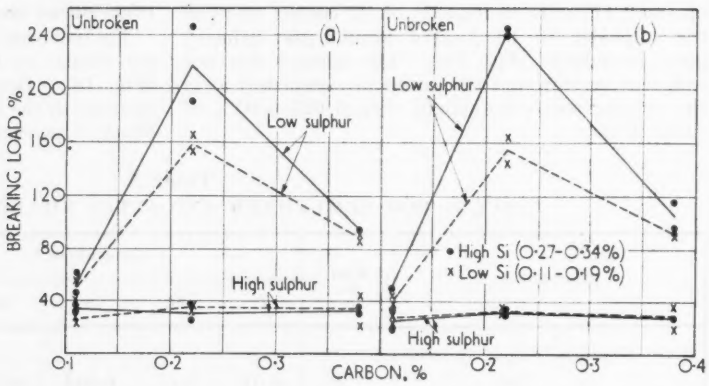

Fig. 20—The effect of carbon on the maximum loads withstood before tearing, for superheats of 50° C. (*a*) No addition of aluminium; (*b*) addition of 4 oz. of aluminium per ton of steel

to 0·056% was to increase the amount of sulphides present (Fig. 19*a*). The introduction of small amounts of aluminium to these steels produced intergranular sulphide films (Fig. 19*b*) similar to those produced in the lower Si-content steels (Fig. 19*c*).

For ease in comparison, all the results have been plotted in Fig. 20. Figure 20*a* shows tearing loads plotted against the carbon content of the steel, for high and low silicon and sulphur content, and without addition of aluminium. As no actual load figures can be stated when the test bar is slightly torn, and as the highest loads recorded were 220 lb., it has been assumed that these test bars were capable of withstanding a load greater than 220 lb. Figure 20*b* shows the results obtained for the series to which aluminium was added.

DISCUSSION OF RESULTS

The series of experiments was arranged to facilitate a statistical analysis,* which showed that the effects of carbon and sulphur are undoubtedly real. The effect of sulphur is overriding, because, with high sulphur content, carbon content has little effect on resistance to tearing. The effect of silicon is also significant, although much less marked; it is greatest with the 0·2% C steel with low sulphur content. The effect of aluminium addition on tearing is quite negligible except in one instance: in the 0·4% C steel, addition of aluminium appears to increase the detrimental effect of higher sulphur content.

In Sections I and II the sulphur steels gave consistently low results, and the effect of increasing the carbon content up to 0·2% was to improve the resistance to tearing. This trend is also evident here, except when the sulphur is high. In such cases the beneficial effect of carbon is annulled by the effect of sulphur. This applies if the silicon content is high or low, *i.e.*, for both semi-killed and fully killed steels.

Figure 20*a* substantiates the beneficial effect of higher silicon content. With steels of equal carbon content and low sulphur content, better properties are obtained when the silicon addition is of the order of 0·25–0·35%.

In Section II it was shown that additions of 0·025–0·05% of Al lowered the tear-resisting properties of high-sulphur steels, owing to the propagation of intergranular inclusions. In this series of experiments the addition of 0·0125% of Al (4 oz. per ton of steel) does not affect the results for high- or low-sulphur steels, because a small amount of aluminium does not influence the nature of the sulphide inclusions. Even with high sulphur content, only small amounts of the intergranular inclusions are produced.

The presence of a considerable number of blowholes in the castings of steels containing the lower silicon content has not greatly influenced their strength, because hot-tearing is mainly dependent on the strength of the cooler surface layer of the casting. Since the blowholes are located internally, they will have little influence on the strength of the bar, the central part of which has very little strength at the time of tearing.

All tests were made at one superheat only (50° C.), The effect of casting temperature on the tearing of killed plain carbon steels is indicated in Table II. from which it appears that, with lower casting temperatures, the order of resistance of the steels may be different.

CONCLUSIONS

The propensity to tearing and the temperature of tearing, in any particular steel, increase with casting temperature. Tearing temperature is also affected by the degree of hindrance to contraction. Steel becomes more susceptible to hot-tearing as its carbon content increases beyond 0·21%. In amounts normally found in commercial steels, phosphorus does not appreciably affect the tearing, but an amount exceeding 0·05% results in a lowering of tear-resisting properties. Nickel, up to 2·4%, lowers the tear-resisting properties, but up to 3·65% no further reduction results. Chromium acts similarly up to 1·8%, but further addition up to 2·55% results in properties better than those of plain carbon steels, for the same carbon content. Steel containing 1·7% of Mn is particularly poor compared with steels containing either lower or higher percentages of manganese. Titanium and vanadium are the most potent elements in improving tear-resisting properties.

* Conducted by the B.I.S.R.A. Operational Research Station and by the Statistical Department of The United Steel Companies, Ltd.

XUM

The higher the sulphur content of the steel, the more susceptible it is to tearing, regardless of the degree of deoxidation. With steels containing 0·042–0·066% of sulphur, small additions of aluminium (0·025%) produce grain-boundary inclusions, with a resultant lowering of the tear-resisting properties. Increasing the aluminium addition in these steels from 0·05 to 0·10% results in a recovery of tear-resisting properties ; a steel to which 0·10% of Al has been added has higher resistance to tearing than a steel containing no aluminium. Additions of up to 0·10% of aluminium to 0·022% S steels apparently have little effect on the sulphide distribution, although giving a progressive improvement in the resistance to tearing.

Large aluminium additions (0·40–0·60%) markedly improve the tear-resisting properties, especially with the higher casting temperatures. The improvement is caused by the effect on the nature of the sulphides, and by the alloying effect of the aluminium.

The change from semi-killed steels with approximately 0·12% of Si to killed steels with approximately 0·3% of Si was accompanied by a small increase in resistance to tearing, most marked in the 0·2% C steel with low sulphur content.

Acknowledgments

The authors thank their fellow research workers, Mr. J. E. Worthington and Mr. P. R. Beeley, for helpful criticism and suggestions ; Professor J. H. Andrew, for permission to use the facilities of the Metallurgical Department of Sheffield University, where the research was conducted ; and the technical staff of that Department, for their assistance.

Thanks are also due to the Members of the Melting and Metallurgical Committee of the Steel Castings Division of B.I.S.R.A., who sponsored the research, for their help and encouragement. The work in Section III was conducted by arrangement with the Ingot Surface Defects Sub-Committee of the Steel-making Division of B.I.S.R.A.

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Table XI

RESULTS OF HOT-TEAR TESTS

(Breaking Loads, given in lb.)

No Aluminium Addition									Addition of 4 oz. of Aluminium per ton of Steel									
0·15–0·20% Si				0·25–0·35% Si					0·15–0·20% Si				0·25–0·35% Si					
0·02% S		0·06% S		0·02% S		0·06% S			0·02% S		0·06% S		0·02% S		0·06% S			
0·1% C	0·2% C	0·1% C	0·2% C	0·4% C	0·1% C	0·2% C	0·4% C		0·1% C	0·2% C	0·4% C	0·1% C	0·2% C	0·4% C	0·1% C	0·2% C	0·4% C	
40 55	155 165	90 85	25 27	32 35	45 20	45 60	190 200	90 90	35 32	25 35	30 35	37 45	145 165	90 90	27 27*	32 35	35 20	50 50*	200 200	95 115	37 20	35 30	25 25*

* Assumed value, as no duplicate test was carried out

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APPENDIX

Statistical Analysis of Hot-Tear Tests

By M. Thomas and G. F. Komlosy

The tests reported in Section III were carried out on the lines of a factorially designed experiment, thus allowing the maximum amount of information to be obtained from the experimental work. In this technique, tests are carried out with the various factors (C, Si, and S contents, and Al addition) at predesigned levels, and not, as in the more conventional manner, with three factors held constant while the fourth is varied. In most cases, duplicate tests were carried out for the various sets of conditions. In three tests, however, a value for the duplicate test has had to be assumed.

The results of such a factorially designed experiment, given in Table XI, lend themselves very favourably to a rigorous statistical analysis.

DETAILS OF ANALYSIS

Two separate methods of analysis, (i) the conventional method due to Fisher, and (ii) a method of factorial regression due to Lyle, were undertaken.

" Four Factors with Replications " Analysis

A table of sums of squares for main and interaction effects is built up by summing the variables in three ways—one, two, and three at a time. An estimate of the residual error is obtained from the replications ; the total number of degrees of freedom has been reduced by three, because three readings had to be assumed as no duplicate test was carried out. The results are as follows :

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
Al	3	1	3
Si	1074	1	1074*
S	69,236	1	69,236*
C	36,719	2	18,360*
Al × Si	34	1	34
Al × S	42	1	42
Al × C	47	2	24
Si × S	999	1	999*
Si × C	540	2	270*
S × C	32,709	2	16,355*
Al × Si × S	89	1	89
Al × Si × C	31	2	16
Al × S × C	191	2	96
Si × S × C	892	2	446*
S × Al × Si × C	7	2	4
Residual	1429	21	68
		45	

* Significant

The main effects of Si, S, and C are significant, but as there are significant interactions (notably Si × S × C) it is necessary to divide the experiment into two 3-factor experiments with the fourth factor taken at its various levels. Three combinations of this were tried—splitting on sulphur, on carbon, and on silicon.

Sums of squares for the main and interaction effects at two levels of sulphur are given in Table XII. At high sulphur (0·06%), no main effects or interaction effects are significant, and variation in other factors will therefore produce no appreciable change in hot-

Table XII

ANALYSIS OF VARIANCE FOR TWO SULPHUR LEVELS

Source of Variance	0·02% S			0·06% S		
	Sums of Squares	Degrees of Freedom	Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares
Al	12	1	12	32	1	32
Si	2072	1	2072*	0	1	0
C	69,368	2	34,684*	60	2	30
Al × Si	117	1	117	7	1	7
Al × C	182	2	91	57	2	28
Si × C	1380	2	690*	55	2	27
Al × Si × C	19	2	10	16	2	8
Residual	769	11	69·9	660	10	66
Total	73,919	22		887	21	

* Significant

tear strength. At low sulphur (0·02%), there are indications of an effect of silicon and a large effect of carbon ; but the Si × C interaction is also significant, which implies that the effect of varying carbon content depends upon the level of Si. This is indicated in Table XIII.

Splitting the experiment on carbon levels yields substantially the same results, although at the 0·4% C level there are indications that aluminium addition gives a significant effect : the interaction term Al × S is significant. This implies that the effect of sulphur at this particular carbon level will differ for the two levels of aluminium (*see* Table XIV). The effect of sulphur is more detrimental at the 0·4% C level if there has been an aluminium addition to the metal.

Factorial Regression Analysis

In this method, the factors C, Al, S, and Si are used as independent variables in a regression upon the dependent variable (hot-tear strength). Considerable simplification of the normal regression technique is obtained if the experiment is factorially designed, and if the intervals between the levels of a particular factor are kept constant. The latter condition is not satisfied in this experiment in the case of carbon, as levels are 0·1, 0·2, and 0·4% C, but satisfactory results are obtained if, in the interpretation of the results, the variable is taken as the logarithm of carbon.

By assigning the values + 1 and — 1 to the levels of sulphur, aluminium, and silicon, and the values + 1, 0, and — 1 to the levels of carbon, the interactions between the independent variables are made zero and the solution of the regression equations is very much simplified. Non-linear effects also can be considered, if the factors are at more than two levels. In this case, carbon is the only factor that can show this effect ; to maintain all interactions zero, therefore, the value $3C^2 - 2$ is used as a variable, instead of C^2, where C represents the particular value assigned to the carbon level under consideration.

The significance of the various factors and interactions is tested by an analysis of variance, as follows :

Source of Variance	Sums of Squares
Al	2·5
Si	1073·5*
S	69,235·5*
C	4232*
C^2	32,486*
Al × Si	35
Al × S	42·2
Al × C	40·5
Al × C^2	7
Si × S	999·2*
Si × C	8·0
Si × C^2	532*
S × C	4006*
S × C^2	28,701
Al × Si × S	88*
Al × Si × C	18
Al × Si × C^2	12
Al × S × C	153·1*
Al × S × C^2	37
Si × S × C	28·1
Si × S × C^2	864*
Al × Si × S × C	3·1
Al × Si × S × C^2	4
Residual	1429* on 21 degrees of freedom†

* Significant
† Degrees of freedom are all unity, except for the residual variance

Table XIII

EFFECT OF SILICON AND CARBON ON TEARING STRENGTH

(Breaking Loads, given in lb.)

C, %	0·15–0·20% Si	0·25–0·35% Si
0·1	44·3	51·3
0·2	157·5	197·5
0·4	88·8	97·5

Table XIV

EFFECT OF ALUMINIUM ADDITION ON TEARING STRENGTH

(Breaking Load, given in lb.)

Aluminium	0·02% S	0·06% S	Difference Between Sulphur Levels
None	88·7	32·5	56·2
4 oz. per ton of steel	97·5	26·2	71·3

Testing the mean squares against the residual error, the following terms remain significant :

Main effects : Si, S, and C (mainly due to C^2)
1st order interactions : Si × S, Si × C (due to C^2), and S × C (mainly due to C^2)
2nd order interactions : Al × S × C (linear) and Si × S × C (mainly due to C^2).

The regression equation for these factors is :

$$Y = 9{\cdot}46Si + 75{\cdot}9S - 23{\cdot}0C - 36{\cdot}8(3C^2 - 2) - 9{\cdot}12(Si \times S) + 1(Si \times C) + 4{\cdot}71[Si \times (3C^2 - 2)] - 22{\cdot}38(S \times C) - 34{\cdot}58[S \times (3C^2 - 2)] + 4{\cdot}37(Al \times S \times C) - 1{\cdot}25[Al \times S \times (3C^2 - 2)] + 1{\cdot}87(Si \times S \times C) + 6{\cdot}00[Si \times S \times (3C^2 - 2)].$$

From the coefficients of this equation it appears that :

(i) Aluminium has no main effect (but two interaction effects require examination)
(ii) The largest effect is due to sulphur
(iii) Carbon has a marked non-linear effect, and best results are obtained at the 0·2% C level
(iv) The presence of silicon is slightly beneficial, but the large interaction terms show that its action is greatly dependent upon the amounts of sulphur and carbon present.

Other effects are deduced by substituting suitable values for the independent variables in the regression equation.

SUMMARY OF RESULTS

(1) The carbon content of steel has been shown to have a considerable effect upon its hot-tear resistance, although the results do not point to a straightforward increase or decrease in strength with increasing carbon. The 0·2% C range appears to be the most effective, and average values of hot-tear strength are 38·25 lb. for the 0·1% C range, 104·93 lb. for the 0·2% C range, and 61·25 lb. for the 0·4% C range.

(2) Addition of silicon is generally beneficial, but its effect is greatly dependent on the amounts of sulphur and carbon present in the steel. This effect is much more marked with 0·02% S and 0·2% C than with S and C contents held constant at their

average values, as is shown by the following figures :

Si, %	Hot-Tear Resistance, lb. Average Contents of S and C	0·02% of S and 0·2% of C
0·15–0·20	63·42	157·5
0·25–0·35	72·87	197·5
Increase	14·9%	25·4%

(3) The presence of sulphur is highly detrimental to the tear-resisting properties, and seems to ' swamp ' the effect of other variables, so that at high sulphur content (0·066% S) the variation of these other factors produces negligible effect on the hot-tear strength. Values of tear resistance for steels containing 0·02 and 0·06% of S are 106·13 lb. and 30·17 lb., respectively. At low sulphur (0·02%), carbon and silicon both influence the results, but the magnitude of each effect depends on the level of the other factors (*see* Table XIII).

(4) If the C, Si, and S contents are held at a fixed value, the effect of adding aluminium (4 oz. per ton of steel) is negligible. However, at the 0·4% C level the addition of aluminium, even in this small amount, appears to produce an effect (*see* Table XIV).

The use of factorial design is greatly recommended for future experiments of this nature, although two points should be borne in mind : the levels should be equi-spaced (*e.g.*, 0·3, 0·6, and 0·9% of Mn), or the spacing should vary according to some mathematical function (*e.g.*, logarithmic : 0·1, 0·2, and 0·4% of C) ; and for a more rigorous and satisfactory analysis, duplicate tests should be made in each set of conditions.

Letter to the Editor

FLOW-PATTERN DETERMINATIONS IN COLD FURNACES

A considerable amount of work on the determination of the field of flow in open-hearth furnaces has now been done on scale models without combustion,[1, 2] and a certain amount of work has been done on operating furnaces.[3] A survey could also be made inside a full-scale furnace before it is fired.[4] A team of four people can carry out a full determination of flow pattern in less than 12 hr. so that steel production is not greatly delayed.

Two trials of the latter type have now been carried out by the Aerodynamics Section of the B.I.S.R.A. Physics Department, and the results will be published after several other designs of furnace have been tested. In the meantime, those wishing to carry out such trials may be interested in a brief description of the technique employed.

The furnaces so far tested have been oil-fired, and the normal flow of steam and oil through the burner was replaced by compressed air. Air was blown through the air system in the normal way.

The relative rates of flow of the air through the jet and the air uptakes were arranged so that the proportion of the total combustion air entrained by the jet was the same in the cold trial as in the hot furnace. This was ensured by making the ratio $\sqrt{\rho G}/M_c$ the same in both trials, where ρ is the density of the furnace gases, G the flux of momentum per second through the burner, and M_c the mass of combustion air entering the furnace per second.

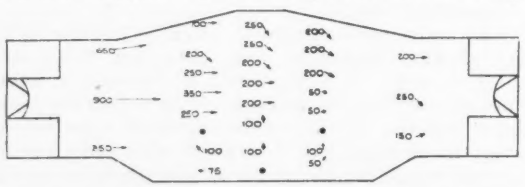
695,000 cu. ft./hr. of air were blown through the air uptakes and 295 cu. ft./min. of compressed air were blown through the gun giving a flux of momentum of 147 ft.lb./sec./sec. in the jet.

The measurements were taken in a rebuilt furnace before firing, and the contents of the bath were simulated by a wooden staging, which also served as a convenient platform on which to work.

The horizontal components of velocities were measured by means of a Metrovick Velometer at 1-ft. intervals above the bath in six different vertical planes along the furnace. The flow direction in the vertical plane was estimated visually using titanium tetrachloride.

The diagram shows the type of flow pattern obtained just below the furnace roof. The forward-flowing stream is particularly strong toward the back of the roof, and the front of the furnace is filled with a slowly moving mass of gas having a certain amount of recirculation. The circles indicate positions of slow indefinite flow.

Erosion of the roof, which took the form of guttering above the tap-hole, occurs in a region where a relatively



fast gas stream, after having struck the bath, flows up the back wall, impinges on the roof, and sweeps in towards the roof centre. More experiments are needed before the full connection between roof erosion and flow pattern is established, and it is hoped that many works will help towards the solution of this problem by carrying out such trials themselves.

British Iron and Steel Research Association, 140 *Battersea Park Road*, *S.W.*11 M. P. Newby, B.Sc., A.Inst.P.

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Note to Authors—The ever-increasing demands on the limited space of the *Journal* have led the Publication Committee to suggest that a section should be devoted to " Letters to the Editor " similar to the above. It is intended that these should be brief notes, describing some new method, apparatus, or important finding that may be of general interest, which do not require the preparation of a full paper or report.

They are intended to replace, rather than to augment, the short papers (2–3 pp.) that appear frequently in the *Journal*, and so to release space for presenting the results of more detailed investigations.

Authors submitting such notes for publication should clearly indicate that they are " Letters to the Editor."

IRON AND STEELWORKS ENGINEERING

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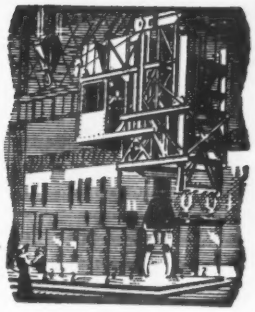

DESCRIPTION OF PLANT

A Gas Cutting Machine for Hot Cropping of Blooms

By W. S. Walker, Ph.D., M.Sc.(Tech.) and A. C. Gerrard

SYNOPSIS

An oxygen cutter has been used to replace hot bloom shears for cropping. The machine has two cutters and two sets of control equipment. It is designed to cut alloy steels up to 30 in. thick at oxygen pressures of 20–35 lb./sq. in. The cutting speed can be varied from 4 to 40 in./min. and one complete operation for a 6¾ in. × 7 in. alloy bloom takes less than 45 sec. It can also be adapted for stainless-steel cutting. The machine has a fume-extraction fan and discharge tracks guide the discards into scrap pans. When not in use the machine is ambushed. The cost per cut is less than for hot saws or shears.

When, in 1945, the installation of a 28-in. rolling mill was in progress at the Atlas Works of Messrs. Thos. Firth and John Brown, Ltd., Sheffield, the use of an oxy-acetylene or oxy-propane cutter as an alternative to the conventional hot bloom shears for cropping the bloom at some point during the rolling cycle was considered to save capital expenditure.

It was anticipated that the mill through-put would be alloy steels, of which 25% would be of heat- and corrosion-resisting qualities. It was envisaged that the average would be 8 to 16 ingots per hr., ranging in weight from 14¾ cwt. to 43 cwt. The ingots would usually be rolled down to a minimum size of 5 in. sq., the discard cropped off, and the prime bloom returned to the mill for continuation of rolling.

The sizes of discards would be such that considerable attention had to be given to their removal from the cropping site to the scrap disposal point.

The qualities of the steels to be handled would call for considerable skill in rolling manipulation and it was most important that the minimum time should be taken to transfer the bloom to the cropping machine, crop it, and subsequently return it to the mill for continuation of rolling.

At this time there was no record that an oxygen cutter had replaced hot shears, although a recent emergency set-up in a rolling mill had utilized an oxygen cutter which, although it required positioning and a considerable amount of manipulation by an operator, had coped with a through-put of 21 to 25 ingots per hour. The only difficulty encountered had been the removal of the discard.

Swarf disposal had been an important item; the best results were obtained when cutting either into a water-filled trough or on to a water-cooled ramp, the slag being carried away by jets of water operating at very high pressure.

Simple tests had shown that the quality of cut obtained by gas cutting was equal, if not in fact superior, to that obtained by shearing, and that an alloy-steel bloom 7 to 9 in. square could be cut in 20 to 30 sec.

Whilst the prime consideration was to provide a machine to crop alloy-steel blooms, attention was paid to cropping the high-chromium steels, and it was decided to experiment with the flux injection technique then being developed in the U.S.A.

The following design requirements for the machine were adopted:

(1) It should be robust and capable of giving continuous reliable service with a minimum of maintenance work.

(2) It should be made with little delay, *i.e.*, by using material which was readily available.

(3) It should be fully automatic.

Manuscript received May 15th, 1951.

Dr. Walker was formerly Technical Engineer to Thos. Firth and John Brown, Ltd., and is now Technical Director at Round Oak Steelworks Ltd., Brierley Hill, Staffs. Mr. Gerrard is at the Atlas Works of Thos. Firth and John Brown, Ltd., Sheffield.

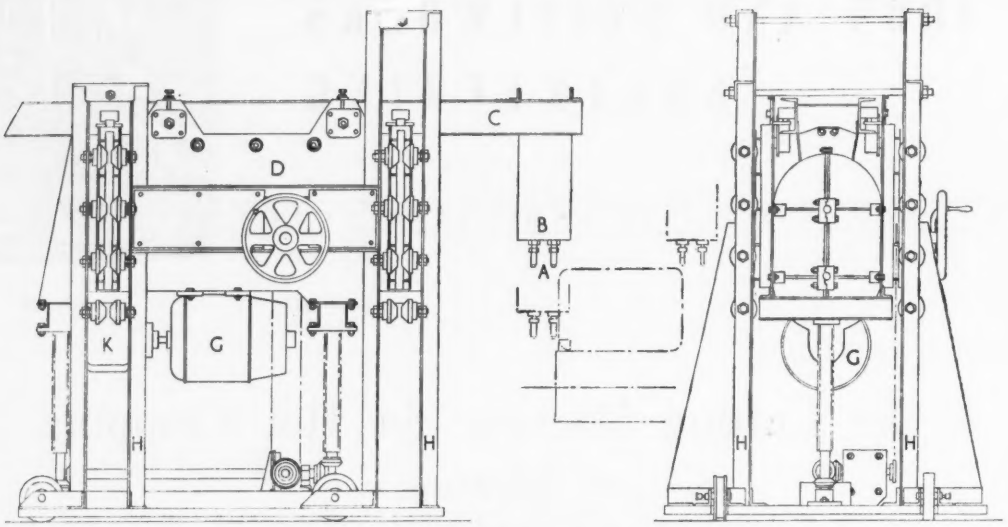

Fig. 1—Arrangement of hot-cropping machine

(4) The design of the mill was such that the whole machine should be capable of being ambushed.

(5) The roll train leading from the mill was designed to operate 2 ft. 6 in. above ground level and the machine design should be such that the cutter height would be readily adjustable to handle material from 5 in. square up to a maximum of 15 in. thick and 22 in. wide.

(6) The machine should be fitted with two cutters and two sets of control equipment as a safeguard against breakdown.

(7) The machine should have oxygen cutters equipped with powder injection attachments for experimental cutting of the high-chromium steels.

(8) The flux distribution unit should be fitted either directly to the machine or adjacent to it, and should carry sufficient flux to cut for a minimum period of one shift without replenishment.

(9) The maximum time permissible for handling the blooms, cutting, and returning to the rolls was 45 sec.

(10) The slag pan should be capable of accommodating the slag from one complete shift's cutting. It should be easy to remove the slag from the pan and to change the pan within the time available between rolling periods.

(11) The removal of the discard from the cutting site to the scrap disposal point should not interfere with the normal working of the mill.

DESIGN OF MACHINE

A machine which fulfils these requirements was designed (*see* Fig. 1). The machine comprises two cutters *A* mounted in a water-coo ledjacket *B*, the whole being mounted at one end of a movable boom *C*. The boom traverses over an assembly *D* by means of a traverse nut moving along a lead screw. A variable-speed motor *G* attached to the base of the assembly *D* drives the lead screw through a gearbox *K*. The whole of the assembly *D* is mounted in a frame *H*, the adjustment of the cutters' height being obtained by moving the whole of the assembly *D* inside the frame. This movement is obtained by two coupled traverse screws operated by lead screws. The lead screws are operated by bevel gears driven from a hand-driven shaft. The boom assembly travels between tapered guide rollers in the uprights of the frame ; these are mounted on Oilite bushes and are fully adjustable to compensate for wear. The main frame is mounted on four flanged wheels, which run on positioned guide rails.

The machine is robust and is capable of withstanding the most arduous operating conditions. It will require the minimum of attention to maintain it in good working condition.

ELECTRICAL EQUIPMENT

The electrical equipment is arranged in two sections :

The Cutter Traversing System—This is operated from the conventional 440-volt, 3-phase, 4-wire system *via* a 3-phase, grid-controlled, mercury-vapour rectifier equipment. The output from this rectifier is used to drive a 2-b.h.p., variable speed, D.C. motor. Through a gear-box, this motor rotates the traversing screw for the cutter head.

The cutting-speed variation is obtained by varying the voltage applied to the motor armature, the range of speed being from 4 to 40 in./min. A safety device returns the grid regulator to the minimum output volts position so that the motor is not started by an excessive D.C. potential, which would probably damage the rectifier bulb and in time the motor also.

The cutter traverse is controlled by limit switches on a timed sequence ; the traverse of the cutter

and the timing of the sequence can be varied within the limits of the machine and the timing relays respectively.

The Gas-Control System—This system is operated from a 440 single-phase circuit (*i.e.*, 2 lines of the 3-phase system), and consists of a combination of electrically operated, pneumatic, timing relays and solenoid-operated valves for gas control.

The timing relays are controlled by a limit switch, which is fixed to the machine and operated by an adjustable striker. By this means the preheat flame is struck at the correct point in the cutting cycle. The duration of the preheat period is controlled, and the introduction of the cutting oxygen towards the end of the preheat period ensures a clean cut with the minimum consumption of gas and loss of time.

Operation—The two systems described above are 'sequence' controlled. The motor drives the boom carrying the cutter until the point of preheat is reached, this being determined by the position of the adjustable striker operating the preheat controls. At this point the motor is stopped and the fuel gas and preheat oxygen are fed on to the cutter by the opening of the appropriate valves in the gas lines.

After a predetermined period, controlled by an adjustable timing relay, the cutting oxygen is applied to the flame by its associated solenoid-operated valve. The boom then carries the cutter forward to complete the operation. At the end of the forward stroke, the length of which is determined by another limit switch, the gas valves are closed by de-energizing the control solenoids and the boom makes the return stroke without further operation of the controls. At the end of the return stroke, the limit switch is again actuated to shut the electrical system down in readiness for the next cutting operation.

Cutting Equipment

The two cutters are designed to cut alloy steels up to 30 in. thick at cutting-oxygen pressures of 20 to 35 lb./sq. in. contrary to the present theory that increased oxygen pressure is required for increased material thickness.

Preliminary tests showed economies in oxygen consumption, and improved cutting speeds when compared with the H.P.-type cutters. The cutters work very satisfactorily without water cooling, and it is thought that if it is subsequently desired to provide water cooling at the nozzle tip, a suitable jacket can be devised. Uncooled nozzle tips simplify changing of nozzles, and if special adapters for dispensing powder for stainless-steel cutting are fitted, these can be attached to the cutters without disturbing their position.

To ensure an adequate supply of oxygen and to minimize the handling of gas cylinders, the existing liquid oxygen line has been extended to a point adjacent to the machine. The works' liquid oxygen plant consists of two coupled 47,000 cu. ft. capacity evaporators which can be used independently or together ; the distance of the hot-cropping machine from the evaporators is 2300 ft. The main oxygen supply pipe is 1 in. bore—and is reduced to $\frac{11}{16}$ in. bore at the valve connecting point, where it is regulated

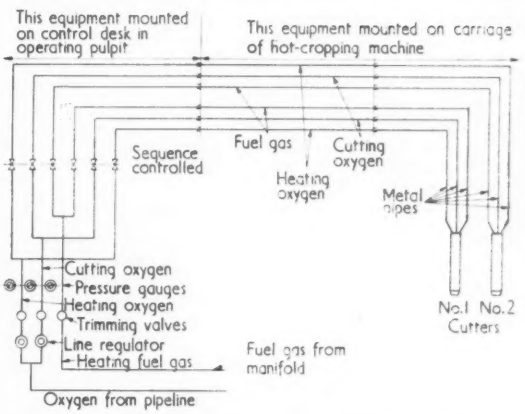

Fig. 2—Control circuit of hot-cropping machine

and passes through a $\frac{3}{8}$-in. bore rubber hose leading to the oxygen-inlet connection on the gas-control cabinet. From here it divides into two lines, one for heating and one for cutting. These again divide and reach the cutting head *via* stop-valve pressure indicators and solenoid-operated control valves. By this means two separate circuits are available, and a single change-over switch allows either cutter to be used without changing any gas feed pipe or electrical connection.

Fuel-gas supplies were originally obtained from three 200 cu. ft. capacity cylinders containing dissolved acetylene coupled together through a three-way cylinder adapter, the gas passing through a two-stage regulator to the gas-control panel. A 100-lb. propane cylinder was also fitted with a two-stage regulator, and was connected to the other fuel-gas duplex connection on the gas-control cabinet (*see* Fig. 2). Suitable stop valves on the duplex connection point of the fuel-gas inlet on the cabinet enable acetylene, propane, or mixed gases to be used. However, with the type of cutters used, mixed fuel gases proved to be unstable and at present propane is used alone. Small pilot lights were at first positioned so that the jets impinged on, but did not affect, the preheat cones of the cutter nozzles. Subsequently, their use has been discontinued, since it was found that the main jet readily ignited from the hot bloom.

Fume Extraction

When cropping certain alloy steels and high-chromium steels, the extraction of fumes is most important. In this machine any system of hood-type fume extraction was prevented by obstructions. However, it was observed that most fumes were carried by the cutting-oxygen stream through the kerf into the slag pan ; an extraction scheme is therefore fitted in this position. It is of necessity a compromise design owing to space restrictions. A motorized extractor fan is fitted in a small cellar adjacent to the cropping site, and from the inlet side of the fan a 6-in. dia. duct connects with a swivelling distributor box on the machine side of the slag pan. A rectangular slot in the slag pan mates with the distributor box. The top of the slag pan is then fitted with a flat

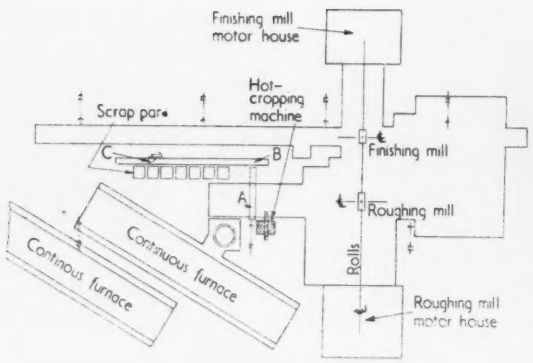

Fig. 3—Mill layout

reinforced cover, which has a slot cut in the top corresponding with the path of the cutter across the bloom. By enclosing the slag pan in this manner, all fumes are confined in the slag pan and then carried away. The swivelling distributor box enables the slag pans to be changed readily.

On the outlet side of the fan a 4-in. dia. pipe takes the fumes to an outlet point in an adjacent furnace stack.

SITING OF THE MACHINE

The position of the hot-cropping machine relative to the general mill layout is shown in Fig. 3. When not in the forward cutting position, it is ambushed behind the line of the adjacent roof-support column. The discards are transferred from the cutting side to the appropriate scrap bins by means of the discharge tracks *A* and *B*. When the discard is travelling along track *B* it is guided into the correct scrap pan by means of the adjustable guide rail *C*. All the machine control equipment is mounted on a platform immediately over the machine. From this position, the machine operator is in full view of the mill control bridge, and is well placed for positioning the bloom accurately and for maintaining visual contact with all the mill activities.

The machine is controlled by a reversible motor driving the rear wheels of the main unit *via* a reduction gear.

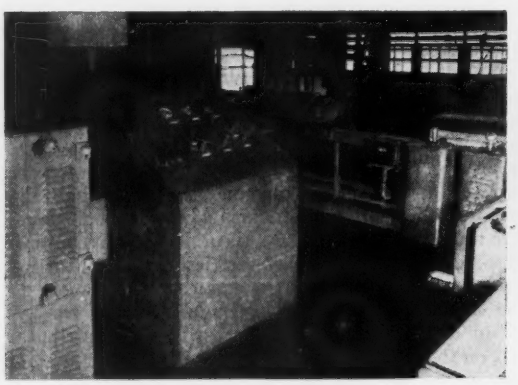

Fig. 4—View of the control platform

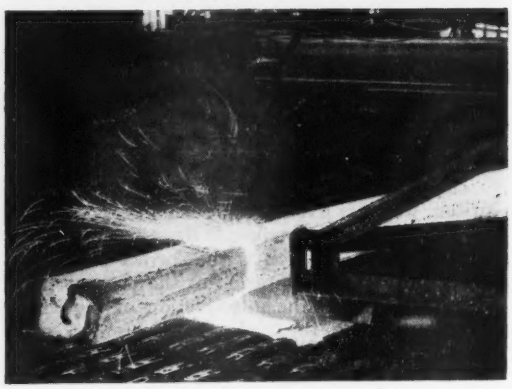

Fig. 5—A cut in progress

Operating Controls

Figure 4 is a general view of the control platform. The mercury arc rectifying cabinet and gas-control panel occupy the centre of the platform, and the pressure gauges, etc., are set at a convenient height for observing and controlling. On the side of the guard rails facing the mill are mounted all the relative controls. Facing the mill and positioned from left to right of the guard rail these controls are :

(i) Coupled change-over switch controlling the entrance rolls to the roughing stand. Normally the entrance rolls are controlled from the main mill control bridge, but when the bloom is ready for cropping, the hot-cropper operator depresses the switches, and by means of a simple forward and reverse lever, operates the rolls and brings the bloom to the correct position for cropping

(ii) The next control governs the position of the machine relative to the mill stage and comprises simple forward and reverse push-button switches

(iii) The fume-extractor motorized fan is controlled next by a push-button on-and-off switch, and at a position in the centre of the guard rail is a switch controlling the forward movement of the cutter-carrying boom and the cutting sequence. This comprises on, off, and reset buttons

(iv) The next control is a simple lever which, when the machine is cutting high-chromium steels, controls the powder flow to the powder-injection nozzle attachment

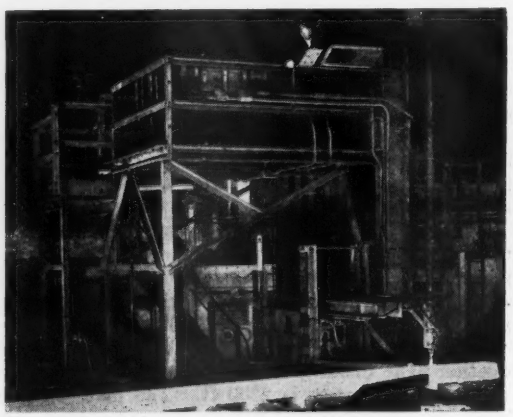

Fig. 6—General view of the machine

Table I

OPTIMUM WORKING CONDITIONS FOR B.O.C., M/C 30, LOW-PRESSURE CUTTER

Nozzle size	$\frac{3}{16}$ in.	
Distance above bloom	$1\frac{1}{2}$–2 in.	
Traversing speed	20–24 in./min.	
Material thickness	7–9 in.	
Preheat cone length	$\frac{3}{4}$–$\frac{7}{8}$ in.	
	Pressure, lb./sq. in.	
	Static	Cutting
Oxygen line regulator	170	146
Propane cylinder regulator	$\frac{2}{3}$	...
Fuel-gas panel	$\frac{1}{2}$	...
Preheat oxygen panel	20	15
Cutting oxygen	78	42
Cutting O_2 cutter gauge	...	35

Table II

TYPICAL OPERATING TIMES FOR CUTTING A $6\frac{3}{4}$ IN. × 7 IN. BLOOM

(Cutting speed $23\frac{1}{2}$ in./min.)

Operation	Time, sec.				
	Cut No.				Average per Cut
	1	2	3	4	
Transfer from rolls to hot cropper	10	10	9	14	10·8
Positioning at hot cropper prior to cutting	6	$6\frac{1}{2}$	4	4	5·1
Preheat period	6	6	6	6	6
Cutting period	18	18	18	18	18
Transfer from hot cropper to rolls	8	$7\frac{1}{2}$	6	6	6·9
Total transfer time	18	$17\frac{1}{2}$	15	20	17·6
Total cutting time	24	24	24	24	24
Total time	42	$41\frac{1}{2}$	39	44	41·6

(v) Finally, two crane-type controllers govern the discharge tracks for the discards.

MACHINE OPERATION

Normally the machine operates continuously from 6 a.m. on Monday until 6 a.m. the following Saturday, and the only rest periods are during the meal breaks of 20–30 min. per shift. Fuel-gas cylinders are changed during the rolling periods without interrupting the use of the machine. When the machine is to be used for alloy-steel cutting after a period of non-usage, the gas supplies and pressures are checked, the speed controls set, and the cutter is correctly positioned.

When these are correct, the machine operation is checked by operating the machine starter fitted to the staging guard rail to ensure that the functioning of the cutting sequence and the pressures recorded on the control panel are correct.

If everything is in order, the machine is then ready to be used as follows :

(1) When the ingot-charging machine has placed the ingot on the entrance rolls and has returned to its waiting position, the machine is brought to a position of readiness just in front of the mill-roll staging

(2) The entrance-roll change-over switches are set

(3) When the bloom has been cogged down to the correct size for cropping, it is accepted on the entrance rolls and brought to a position that ensures that the correct amount of discard will be cut off

(4) The machine is brought forward until the machine pusher-bar is in contact with the bloom

(5) The cutting sequence is started

(6) When the discard has fallen on to the discharge track, the gases have been automatically cut off, and the bloom is returning to its starting position, the return control is operated to ambush the machine

(7) The bloom is returned to the mill rolls by means of the entrance-roll control

(8) This control is then transferred to the main bridge

(9) The movement of the discharge tracks is started

(10) When the discard has been ejected into the scrap pan, movement of the discharge tracks is stopped. Everything is then ready to start the next cycle of operations.

Table III

COMPARATIVE COSTS OF CUTTING A 7 IN. × 7 IN. BLOOM BY DIFFERENT METHODS

	Oxygen Cropping Machine		Hot Saw		Shears	
Estimated capital cost	£2,000		£4,000		£30,000	
Amortization and interest on capital:						
Yearly rate	£250		£500		£3750	
Hourly rate*	10·0 pence		20·0 pence		150·0 pence	
Cost per cut, pence:						
Amortization, etc. (16 cuts/hr.)		0·625		1·250		9·375
Material used	Gas	2·167	Saw	1·8	No information available	...
Power, at 0·55 pence per unit	2 h.p. 1 min. per cut	0·014	15 h.p. running light 100 h.p. cutting 14 sec. per cut	0·52	50 h.p. running light 200 h.p. cutting 7 sec. per cut	1·4
Waste of material, at £15 per ton	Kerf, $\frac{3}{16}$ in. wide	4·1	Kerf, $\frac{1}{4}$ in. wide less credit for returned swarf at £3 per ton	4·32	None	0
Total†		6·906		7·890		10·775

* Hourly rate based on 8-hr. shifts, 15 shifts per week, 50 working weeks per year

† Total excludes wages of one man and shop overheads ; these are the same for each machine

A cut in progress is shown in Fig. 5 and a general view of the machine in Fig. 6.

Working Results

During the first few weeks of installation, information was obtained on gas pressures, cutting speeds, and so on, which decided the subsequent cutting conditions. The majority of blooms that are cut are between 7 and 9 in. thick, and for these the conditions given in Table I are most suitable.

Fuel-gas pressures vary slightly but the preheat flame is checked at the commencement of each shift by adjusting these pressures.

When the machine was first designed, it was specified that the maximum time that could be allowed for the movement of the bloom from the mill to the hot cropper, cropping, and returning to the mill, should not exceed 45 sec. The actual operational times given in Table II show that the average operating times are less than this figure, and it is hoped that, as the operators become more skilled in positioning the blooms, an average figure of about 35 sec. would be regularly achieved. This has been borne out in the 22 months in which the machine has been in continuous use, during which period approximately 80,000 cuts have been made.

These existing operational times fit in well with the cycle of mill operations, but it is important that the normal time-cycle of mill operations should be kept in mind when considering the possible use of a hot-cropping machine. Hot cropping has numerous advantages over either hot saws or shears under the present time-cycle of mill operations at this specific mill, but in the event of a reduction of this time-cycle the use of shears may be essential.

It would appear that the hot-cropping process will bear comparison, from the economic point of view, with hot sawing and shearing. Table III gives the approximate costs per cut for cutting a 7 in. × 7 in. bloom by the three methods.

Acknowledgments

The authors are indebted to the Directors of Thos. Firth and John Brown, Ltd., for permission to publish this paper, and to their colleagues and members of the British Oxygen Co., Ltd., for assistance throughout with the design, manufacture, and commissioning of the machine.

POST-GRADUATE COURSES IN STRUCTURE AND STRENGTH OF MATERIALS

A post-graduate course in Theory of Structures and Strength of Materials, extending over one year (October to June) will begin at the Department of Engineering, Cambridge University, on 8th October, 1951.

During the past twenty years great advances have been made in the understanding of the behaviour of metallic structures, as the result of researches into fundamental problems encountered in the application of welding as a method of fabrication. The progress achieved is not adequately reflected in present-day practice because design and construction are governed by rules and specifications which of necessity are always somewhat conservative.

The purpose of the course is to give engineers with some industrial experience a sound and critical appreciation of modern ideas on the design of all kinds of welded structures and the properties of materials required in welded fabrication. These subjects cannot receive adequate attention in engineering undergraduate courses because of their advanced and specialized character.

No attempt will be made to teach conventional methods of design but present-day practice, here and abroad, and possible future developments will be the subject of critical study. It is not the object of the course to train research workers but engineers of independent outlook, who can apply the latest advances in knowledge.

The subjects will be covered by lectures, colloquia, and laboratory work. Each student will be required to make a number of reports on specialized subjects and will be encouraged to make a detailed theoretical and experimental study of some problem of particular interest to him. The reports and results of individual studies will be made available to all participants and will be discussed *in colloquia*. In this way each student will benefit not only from his own work but also from that of his colleagues.

In addition to the design and analysis of framed structures the syllabus includes the following items of special interest to the metallurgical engineer :

Materials : Mechanical properties—Theory of plasticity—Plastic properties—Dynamic properties of materials (impact and fatigue)—Notch brittleness—Temper brittleness—Ageing—Corrosion

Welding : Welding methods—Weld metals—Fundamentals of welding metallurgy of ferrous and non-ferrous metals—Distortion and residual Stresses—Inspection and testing.

The course is open to University graduates with industrial experience, and also to students who have suitable equivalent qualifications.

Applications for admission should be sent to the Secretary, Faculty Board of Engineering, Engineering Laboratory, Cambridge, from whom further particulars may be obtained.

TRANSFER OF RESEARCH TO SCOTLAND

Some of the work being done in the Engineering Division of the National Physical Laboratory is being transferred to the new laboratory of the Mechanical Engineering Research Organization, D.S.I.R., at East Kilbride, Nr. Glasgow.

The main section of the research work to be transferred is that concerned with the strength of materials at ordinary temperatures, including fatigue of materials, failures in service, mechanical design problems, gas cylinders, mechanical tests on metallic and non-metallic materials, and general mechanical testing techniques. For the time being the work on the strength of materials at high temperatures will remain at the N.P.L. but it is scheduled to move to Scotland later.

The headquarters of the Organization, together with the Lubrication Division, the Machine Shaping Section and parts of the Mechanisms and Formation Section, have been at Thortonhall, Glasgow (a few miles from East Kilbride), for some time.

Enquiries relating to the strength and properties of materials at ordinary temperatures should now be addressed in the first place to The Director, Mechanical Engineering Research Laboratory, East Kilbride, Glasgow.

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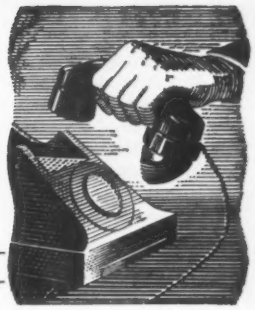

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE
Special Meeting in Austria, 1951

A Special Meeting of the Institute is to be held in Austria, from **5th to 18th September, 1951,** at the invitation of the Austrian Iron and Steel Institute (Technisch-Wissenschaftlichen Verein Eisenhütte Oesterreich).

The Council of the Institute of Metals have invited Members of The Iron and Steel Institute and their Ladies to attend their Annual Autumn Meeting, which is being held in Italy from 16th to 25th September, 1951. A similar invitation to attend the Meeting in Austria has been extended to Members of the Institute of Metals.

Provisional details of the meeting have already been given in earlier issues of the *Journal* (Feb., and May, 1951) and in a circular distributed to all members. The following abridged programme is provided for reference.

Programme

Members will arrive at Gmunden on the evening of **Thursday, 6th Sept.** The Meeting is divided into three sections for the convenience of Members who wish to attend only part of the proceedings: (1) from 6th–8th Sept., at Gmunden; (ii) from 9th–15th Sept., at Graz and Pörtschach; (iii) 16th–18th Sept., at Zell-am-See. Members taking part in the Italian Meeting will leave after lunch on 15th Sept.

Friday, 7th Sept.

Visits to:

Vereinigte Oesterreichische Eisen- und Stahlwerke A.G., Linz (Iron and Steel Works)

Vereinigte Aluminium Werke A.G., Mattigwerke, and

Oesterreichische Metallwerke, Ranshofen (Electrolytic extraction of aluminium).

In the afternoon there will be a steamer excursion on the Danube. The evening will be free in Gmunden.

Saturday, 8th Sept.

Visit to Veitscher Magnesit A.G., Trieben (Magnesite products).

The day will end in Graz with the evening free.

Sunday, 9th Sept.

The whole day will be free in Graz.

Monday, 10th Sept.

There will be an Official Welcome at the Stefaniensaal in Graz, followed by Luncheon in the Schlossberg given by the Austrian Iron and Steel Institute. In the afternoon there will be a Technical Session with the Austrian Iron and Steel Institute, held in the Stefaniensaal. The programme will include the presentation and discussion of the paper by F. Rapatz and M. Strobich entitled "*Investigations into the Effect of Non-Metallic Inclusions on the Hot-Workability of Steel*," and the presentation of a lecture by Dr. J. H. Chesters on "*Recent Advances in British O-H. Furnaces: A Pictorial Review of Progress in Aerodynamics, Refractories, and Combustion.*" The Lecture will be illustrated with a film on "*Fluid Flow*" followed by discussion.

Ladies will take a motor-bus excursion.

A Reception and Buffet at the Burg will be given in the evening by the Governor of the State of Styria.

Tuesday, 11th Sept.

Visits to:

Montanistische Hochschule, Leoben

Oesterreichisch-Alpine Montangesellschaft, Donawitz (Iron and Steel Works).

Ladies will take a motor-bus excursion. In the evening there will be a Reception and Dance in the Redoutensaal, given by the Mayor of Graz.

Wednesday, 12th Sept.

Members and Ladies will visit the Erzberg. The evening will be free in Graz.

Thursday, 13th Sept.

Visits to:

Gebrüder Böhler A.G., Kapfenberg (Steelworks and foundry)

Oesterreichisch-Alpine Montangesellschaft, Kindberg (Rolling mills and tube works)

Felten und Guilleaume A.G., Bruck (Wire drawing)

Schoeller-Bleckmann Stahlwerke A.G., Hönigsberg-Mürzzuschlag (Alloy and special steels)

Elin A.G., für Elektrische Industrie, Weiz (Electrical equipment)

Steyr-Daimler-Puch A.G., Graz (Motor cycles and bicycles)

Andritzer Maschinenfabrik A.G., Graz (Foundry, heavy machinery).

Ladies will take part in a motor-bus tour. The evening will be free in Graz.

Friday, 14th Sept.

Members and Ladies will travel by bus from Graz to Pörtschach.

Visit to Kärntnerische Eisen- und Stahlwerke A.G. (Iron, copper, and aluminium wire-drawing) and to the Guild of Gunmakers, Ferlach.

In the evening there will be a Reception and Buffet in the Park Hotel, Pörtschach, given by the Governor of the State of Carinthia.

Saturday, 15th Sept.

Visits to:

Oesterreichisch-Amerikanische Magnesit A.G. Redenthein (Magnesite products)

Bleiberger Bergwerksunion, Bleihütte Gailitz (Lead and zinc products)

Ladies will visit the Ossiacher See. After returning to Portschach the afternoon will be free to Members and Ladies.

In the evening there will be a Dinner and Dance in the Park Hotel, Portschach.

Members joining the Institute of Metals Meeting in Italy will leave for Venice.

Sunday, 16th Sept.

Members and Ladies will travel by bus over the Grosslockner Strasse to Zell-am-See, where the evening will be free.

Monday, 17th Sept.

Members and Ladies will visit the Tauern-Kraftwerke A.G., Kaprun (Hydro-electric power station) The evening will be free in Zell-am-See.

Tuesday, 18th Sept.

After the free morning in Zell-am-See, Members and Ladies will return to London.

Reception Committee

An Austrian Reception Committee has been formed, with Dr. J. Oberegger (*see* frontispiece) as Chairman. Professor R. Walzel is Chairman of the Executive Committee, and is also Joint Honorary Secretary, with Lt.-Col. N. Watson, of the Reception Committee.

Dr. Richard Walzel was born in Neunkirchen, Austria, in 1895. He received his technical education at the Montanistische Hochschule, Leoben, and graduated as Dipl.-Ing. in 1920. He later received the award of Dr. mont.

During the next thirteen years he held various technical positions in the Austrian iron and steel industry, finally becoming Director of Research to the Oesterreichisch-Alpine Montangesellschaft. In 1933 Dr. Walzel was appointed Professor of Ferrous Metallurgy at the Montanistische Hochschule, a position which he still holds. He is Chairman of the State Examinations Board for Ferrous Metallurgy at Leoben, and is Vice-President and Honorary Secretary of Eisenhütte Oesterreich (the Austrian Iron and Steel Institute).

Lt.-Col. Nigel Watson, O.B.E., of the Oesterreichisch-Alpine Montangesellschaft, was formerly with the Economic Division of the Allied Commission for Austria, being responsible for the mining and metallurgical work in the British Zone.

As Joint Honorary Secretary of the Executive Committee Col. Watson has closely collaborated with the Institute in the arrangements for the Special Meeting in Austria, and his close liaison with the leading Austrian industrialists has been of great assistance in determining the detailed programme of visits and excursions.

The Ladies Reception Committee is headed by Mrs. Oberegger.

The Austrian Iron and Steel Institute

The Austrian Iron and Steel Institute (Technisch-Wissenschaftlichen Verein Eisenhütte Oesterreich) was formed in 1925 under the Presidency of Dr. Anton Apold, General Manager of Oesterreichisch-Alpine Montangesellschaft. Its objects were to provide a common meeting ground for the metallurgists and engineers of the Austrian iron and steel industry and to provide a liaison between the industry and the University of Leoben (Montanistische Hochschule).

Largely due to the energies of Professor Othman von Keil-Eichenturm, one of the first two Vice-Presidents, the Institute became internationally recognized as an important technical society. In 1933 Professor R. Walzel became Vice-President and Honorary Secretary.

The Institute, from the start, co-operated with the Verein Deutscher Eisenhüttenleute, Dusseldorf, and this liaison became even closer during the war period from 1938–1945. However, after the war a reorganization was necessary and the present form of the Institute was re-inaugurated in February, 1950 under the Presidency of Dr. J. Oberegger. The Vice-Presidents are Dipl. Ing. Hans von Pengg-Auhein and Professor R. Walzel, the latter also continuing as Honorary Secretary.

An international conference was held in June, 1950, attended by delegates from nine countries. The annual general meeting (Eisenhüttentag) was again held in June, 1951 and in September, 1951 the Institute is to be host to the British and foreign members of The Iron and Steel Institute.

Bessemer Medal, 1951

The Bessemer Medal for 1951 was presented to Dr. Benjamin F. Fairless, President of the United States Steel Corporation, at the 59th General Meeting of the American Iron and Steel Institute on 24th May, 1951.

The photograph shows Sir Charles Goodeve, F.R.S., an Honorary Member of Council and Director of the British Iron and Steel Research Association, presenting the Medal to Dr. Fairless.

Andrew Carnegie Scholarships

The following awards have been made :

Mr. J. P. HUGO (Sheffield University) : £150 to carry out an investigation on " The Tensile Properties of Aggregates of Ferrite and Pearlite."

Mr. B. CINA (Sheffield University) : £150 for work on " The Immediate Effect of Cold Work on the Gamma ⇌ Alpha Transformation Characteristics of the Fe–Cr–Ni Alloys."

Mr. J. BURKE (Liverpool University) : £50 to carry out work on " The Decomposition of the Carbide Constituent in High-Purity Cast Irons."

Mr. S. GARBER (Sheffield University) : £250 to carry out work on " The Formation of Graphite in Cast Irons."

NEWS OF MEMBERS

▶ Mr. K. W. J. BOWEN has been awarded the Ph.D. degree of the University of Cambridge.

▶ Mr. R. W. FIRTH has left the David Brown Foundries Co. to join the staff of Messrs. Sagar-Richards, Ltd., Halifax, as assistant to the Technical Director.

▶ Mr. S. FORNANDER, Research Metallurgist at the Surahammar Steelworks, has been appointed Director of Research of Jernkontoret, Stockholm, in succession to Dr. Magnus Tigerschiöld, with effect from 1st January, 1952.

▶ Dr. R. GENDERS is now associated as Consultant Metallurgist with Messrs. Sandberg, of 40 Grosvenor Gardens, S.W.1, in connection with their recently re-opened analytical and testing laboratories.

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▶ Mr. C. S. GILL, Managing Director of the Davy and United Roll Foundry Ltd. and Past-Chairman of the Back-up Roll Makers' Association, has been presented with Sheffield Plate by the Association.
▶ Mr. J. M. HINDE has taken up an appointment with Canadian Refractories, Ltd., Quebec, Canada.
▶ Mr. A. HUNTER has transferred to the Workington Iron and Steel Co., a branch of The United Steel Companies, Ltd., as electrical engineer (maintenance).
▶ Mr. H. F. JEFFRIES has left the Karabük Iron and Steel Works in Turkey, and has returned to England.
▶ Mr. S. V. JONES has joined the Furnace Contracts Department of the Wellman Smith Owen Engineering Corporation, Ltd., London.
▶ Mr. J. MACKENZIE has been appointed Works Metallurgist with the Perfection Piston Manufacturing (Pty.), Ltd., Roodepoort.
▶ Sir ARTHUR MATTHEWS (Member of Council) has resigned from all executive positions held with Thos. Firth and John Brown, Ltd., Sheffield, as from June 16th.
▶ Mr. J. A. MENZIES has left Messrs. Colvilles, Ltd., Glasgow, and is now on the research staff of Messrs. Babcock and Wilcox, Ltd., Renfrew.
▶ Dr. F. R. MORRAL has resigned his appointment with the Engineering University, Syracuse, N.Y., to join the Metallurgical Research Department of the Kaiser Aluminium and Chemical Corporation, Washington.
▶ Mr. A. H. POPLE has been appointed Fuel Technologist at the Cable Works of Messrs. Guest Keen Nettlefolds, Ltd., Cardiff.
▶ Mr. I. SAHLIN, Assistant Director of Research of Jernkontoret, Stockholm, will relinquish this post at the end of September to become Counsellor of Commerce (Kommerseråd).
▶ Mr. A. W. SWAN has left The United Steel Companies Ltd., to take up an appointment with Messrs. Courtaulds, Ltd., Coventry.
▶ Dr. C. SYKES (Member of Council) has succeeded Sir Arthur Matthews as Managing Director of Thos. Firth and John Brown, Ltd.
▶ Mr. I. WILLIAMS, Assistant Manager of the Continuous Pickling and Hot Sheet Finishing Departments at the Ebbw Vale Works of The Steel Company of Wales, Ltd., has been appointed Assistant to the Plant Manager at the Trostre Works of the Company.
▶ Mr. S. R. WILLIAMS has been appointed an editorial assistant with the Institute of Metals.
▶ Mr. A. J. WILLIAMSON, formerly Plant Manager with the Columbia Steel and Shafting Co., Pittsburgh, is now Vice-President of the Tube Reducing Corporation, Wallington, N.J., U.S.A.

CONTRIBUTORS TO THE JOURNAL

S. C. Britton—Head of the Corrosion Laboratory of the Tin Research Institute. After graduating at Cambridge University, where he had been an Exhibitioner of Pembroke College, Mr. Britton entered Dr. U. R. Evans' laboratory in 1929 and was associated with corrosion research there until 1935. He then joined the Research Department of the London, Midland, and Scottish Railway where, with the exception of the four war years spent in the Operational Research Section of Bomber Command, he remained until he took up his present appointment in 1948.

R. M. Angles—A member of the Corrosion Laboratory of the Tin Research Institute. Mr. Angles joined the Tin Research Institute in 1933 after leaving the Tiffin Boys' School. He continued his technical studies at Northampton Polytechnic. He has been engaged principally in the investigation of the electrodeposition and properties of coatings of tin and its alloys, and has been associated with many publications in this field.

THE IRON AND STEEL ENGINEERS GROUP

The **Sixteenth Meeting** of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1, on **Tuesday, 4th December, 1951.**

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Corrosion of Buried Metals

A joint meeting of the British Iron and Steel Research Association and the newly formed Corrosion Group of the Society of Chemical Industry will be held at the offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 12th December, 1951.

The following papers will be presented for discussion :

"*Tests on the Corrosion of Buried Iron and Steel Pipes*," by J. C. Hudson and G. P. Acock
"*Protection of Cast Iron Pipes in Clay Soils*," by K. R. Butlin, W. H. J. Vernon, and L. C. Whiskin
"*Behaviour of Aluminium and Its Alloys in Soils*," by E. W. Skerry
"*Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils*," by G. Mole
"*Tests on the Corrosion of Buried Aluminium, Copper, and Lead*," by P. T. Gilbert and F. C. Porter
"*Cathodic Protection of Buried Metal Structures*," by M. R. de Brouwer
"*Cathodic Protection*," by K. A. Spencer.

The papers, with the proceedings of the meeting, will later be issued in the Special Report series of the Institute. Advance copies of the papers will be available before the meeting. Those wishing to take part in the meeting are asked to apply for registration forms to the Secretary of The Iron and Steel Institute.

Conference on Acid Economy

The Coatings Committee of the Mechanical Working Division organized a Conference on Acid Recovery which was held on 6th June at Sketty Hall, Swansea. Five papers, prepared by the staff of the Association, were presented and discussed. They outlined methods of economizing in the use of sulphuric acid in the pickling of tinplate and sheet. The lively discussion that followed indicated that the industry and the Association were fully aware that a solution to the problem of the present acute acid shortage should be found without delay.

Seventh Plant Engineering Conference

A conference was held at Church House, Westminster, on 13th and 14th June, to discuss the mechanical engineering aspects of rolling-mill design. Special reference was made to operating experiences in a number of modern installations.

MEMOIRS

Arthur Crooke died on 30th April, 1951. He was born in Stockton-on-Tees in 1868. In 1886 he started work as an engineering apprentice with the Millom and Askham Hematite Iron Co. He joined the Frodingham Iron and Steel Co., Ltd., in 1893, as Blast-Furnace and Mines Manager and later became Joint General Manager. With the formation of the Appleby-Frodingham Steel Co., Ltd., Mr. Crooke became General Manager. He was later appointed Director and General Works Manager

and at the time of his retirement in 1943 he was Technical Director of the Company. Mr. Cooke was for many years Chairman of the National Council of Associated Iron Masters, and was at one time Chairman of the Lincolnshire Iron Masters' Association, and President of the Lincolnshire Iron and Steel Institute. He was elected a Member of The Iron and Steel Institute in 1895 and was an Honorary Life Member. He was awarded the Williams Prize in 1928 for a joint paper on "New Plant of the Appleby Iron Co., Ltd."

Oswald H. Wass died on 27th April, 1951. From 1909 Mr. Wass was successively employed in the melting departments of the following steelworks: Earl of Dudley's Round Oak Works, John Lysaght, Ltd., Scunthorpe, The Lancashire Steel Corporation, and the Special Steel Co., Ltd., Sheffield. In 1924 he joined General Refractories, Ltd., as technical representative for West Yorkshire and Lancashire. He transferred to the Head Office in 1929 to deal with the Company's sales in Yorkshire and North Lincolnshire, and at the time of his death he was Chief Outside Sales Representative. Mr. Wass was elected a Member of The Iron and Steel Institute in 1936.

James Raymond Young died on 5th January, 1951. He was born in 1894 at Stawell, Australia, and was educated at Stawell Public School and Stawell School of Mines, where he obtained a diploma. In 1913 he joined the Broken Hill Proprietary Co., Ltd., as a chemist at Port Pirie, and transferred to the Company's Steel Works at Newcastle, N.S.W., two years later. He was a member of the technical staff at the Coke Ovens Department and became superintendent of the Blast-Furnace Department in 1924. In 1935 he was appointed to the Administrative Executive Staff. He was elected a member of The Iron and Steel Institute in 1935 and was also a member of the Australian Institute of Mining and Metallurgy and of the Australian Institute of Metals.

NEWS OF SCIENCE AND INDUSTRY

Société Française de Métallurgie

The Autumn Conference of the Société Française de Métallurgie will be held in Paris from 22nd to 27th October. The Société is anxious to have the collaboration of Metallurgical Scientists from abroad. Those interested are invited to write to the Société Française de Métallurgie, 5 Cité Pigalle, Paris, 9ème.

Members of The Iron and Steel Institute or of the Institute of Metals are reminded that they may pay a reduced subscription rate for membership of the Society. The rate for such joint members is 700 frs.

Members may also subscribe to the Revué de Métallurgie at the reduced rate of 7.900 frs. instead of 10.000 frs. This subscription also includes the annual list of members.

Spanish Iron and Steel Institute

The Spanish Iron and Steel Institute will hold a conference in Madrid from 10th to 15th December. This will be preceded by group visits to important industrial concerns in other localities where conferences connected with them will be held.

Research Fellowship in Metallurgy

The Secretaries of the Royal Society are prepared to receive applications for the above Research Fellowship in Metallurgy of the Royal Society, Armourers and Brasiers' Company.

The successful candidate will be required to enter upon and devote his whole time to a course of research which must be connected with base metals and alloys, and preferentially those used in connection with the Ancient Crafts of the Company of Armourers and Brasiers. The Research is to be carried out under the scheme approved by the Royal Society and the Armourers and Brasiers' Company, particulars of which can be obtained from the Royal Society.

The appointment will be for two years in the first instance from 1st October, 1951, but may subsequently be extended to a maximum of five years. The stipend will be £850 per annum with superannuation benefit.

Further particulars may be obtained from the Assistant Secretary of the Royal Society, Burlington House, London, W.1.

Jernkontoret

Mr. S. FORNANDER, Research Metallurgist of the Surahammar Steelworks, has been appointed Director of Research of Jernkontoret in succession to Dr. MAGNUS TIGERSCHIÖLD who has taken up an appointment with Trafikaktiebolget Grängesberg-Oxelösund. Mr. Fornander will take up his new duties on 1st January, 1952, and until this date Mr. E. ÖHMAN will be in charge.

Mr. I. SAHLIN, for many years Assistant Director of Research of Jernkontoret, has been appointed Counsellor of Commerce (Kommerseråd), and will leave Jernkontoret at the end of September, 1951. He will be succeeded by Mr. K. F. LINSTRAND, at present with the Degersfors Steelworks.

DIARY

6th–15th Aug.—BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE—Annual Meeting—Edinburgh.

30th Aug.–13th Sept.—ENGINEERING, MARINE AND WELDING EXHIBITION—Olympia, London, W.14.

TRANSLATION SERVICE

(The previous announcement was made in the July, 1951, issue of the *Journal*, p. 304).

TRANSLATIONS AVAILABLE

No. 421 (German). W. PAPSDORF: "Patenting and Drawing Experiments on Austenitic Coarse- and Fine-Grained Steel Wires and the Influence of Small Contents of Carbide-Forming Alloy Elements." (*Archiv für das Eisenhüttenwesen*, 1951, vol. 22, Mar./Apr., pp. 87–98).

No. 422 (Russian). B. D. AVERBUCH and G. E. CHUFAROV: "Kinetics of Decarburization of Transformer Steel during Annealing with Hydrogen." (*Metallurg*, 1939, No. 7, pp. 48–61). (Translation made available through the courtesy of the British Iron and Steel Research Association. Members of that Association may obtain copies free of charge on application to B.I.S.R.A.).

TRANSLATIONS IN COURSE OF PREPARATION

(Czech). A. BENDA: "Thermal Analysis of Open-Hearth Furnace Operation." (*Hutnické Listy*, 1950, vol. 5, Nov., pp. 454–457).

(Czech). L. KUČERA: "Colorimetric Determination of Silicon in Malleable Cast Iron." (*Hutnické Listy*, 1950, vol. 5, June, Supplement No. 2, pp. 102–106).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

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ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Iron Ores of the Lahn-Dill Region. E. A. Scheibe. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 954–956). The geology of the Lahn-Dill region and the formation of the iron ores therein are discussed. The important yearly output of 700,000 tons comes from many small mines. The reserves are estimated to last 50 years.—J. P.

The Iron Ore Deposits in South Baden. R. Geisler. (Stahl und Eisen, 1950, vol. 70, Nov. 9, pp. 1057–1059). The geographical situation, the geology of the strata, and the historical development of mining in South Baden are briefly reviewed.—J. P.

American Quest for Iron Ore. M. S. Krishnan. (Journal of Scientific and Industrial Research, 1950, vol. 9, Nov., pp. 395–405). World reserves of iron ore are reviewed. American production and recent improvements in technique are discussed. The present sources of iron ores and the discovery and development of new deposits are considered. The author points out that India should profit by the experience of America and economize with iron ore deposits.—J. P. S.

ORES—MINING AND TREATMENT

Trackless Mining Improves Ore Production for TCI. L. H. Johnson. (Mining Engineering, 1950, vol. 187, Dec., pp. 1225–1229). The development and special features are described of a system of trackless underground mining for iron ore as operated by the Tennessee Coal, Iron and Railroad Co. in the Birmingham, Alabama, district. Mining is highly mechanized and involves electrically powered crawler-mounted loaders, air-operated rubber-tyred drill carriages, and rubber-tyred shuttle cars. Details are given of the system of roof bolting used exclusively for roof support. A multiple-entry panel mining system is used and layout and mining plan are explained.—E. C.

Opening the Pyne Mine of the Woodward Iron Co. J. V. Beall. (Mining Engineering, 1950, vol. 187, Dec., pp. 1230–1235). An account is given of the layout, operation, and equipment of the Pyne iron ore mine in the Red Mountain Range near Birmingham, Alabama. Panel mining is employed with a multiple heading development cycle. Both single and double-wing stopes are developed and roof bolting is practised. For ventilation the split system has been adapted from coal-mining practice. Surface equipment includes primary and secondary crushers and screening plant.—E. C.

Iron-Ore Mining in the Scunthorpe District: Mechanical Aids to Production. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 8, pp. 877–878). The author briefly compares the following methods of stripping the overburden in use in the Scunthorpe iron-ore mining district: (1) Long-reach shovels; (2) digger transporter combinations; (3) single draglines; (4) dragline transporter combinations; (5) multiple draglines; and (6) wheeled scrapers. Drilling, blasting, loading, and hauling are briefly considered, and finally some of the long-term reasons for controlling the outputs from individual pits, in cases where a number of pits are controlled by one company, are indicated.—G. F.

Drying of Ironstone: Techniques Utilised at Appleby-Frodingham. R. C. Walthew. (Institute of Fuel: Iron and Coal Trades Review, 1951, vol. 162, Jan. 19, pp. 155–157). At the Appleby-Frodingham Steel Co., the Northamptonshire iron ore is partially dried before charging into the blast-furnace, chiefly to facilitate the grading and handling of the ore. The author describes the drying technique and gives brief details of operating results and of the heat balance of the process. The main problem is dust emission, and methods of reducing this, in particular the avoidance of over-drying, are considered. Future trends are most likely to be in the direction of more comprehensive instrumentation and closer operational control, in view of the importance of fuel economy and of ensuring optimum drying conditions.—G. F.

Sinter Making at Appleby-Frodingham. G. D. Elliot and N. D. Macdonald. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 261–272). A large-scale plant research has been carried out with the aim of improving the quality of sinter manufactured from Frodingham and Northampton ironstone fines. Several aspects of plant, raw materials, and practice are briefly dealt with; the effects o return fines, which are shown to be of great importance in sinter making, are discussed at greater length. Arising from this work, modifications are being made to a new sintering plant that is being built. These are mentioned but are not described.

Mining and Steel Industry in Nassau and Siegerland. K. Grethe. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Sept. 4, pp. 687–690). Following a geographical and historical description of the two industrial and mining districts, a survey is given of the present output of ore, steel, and by-products.—J. G. W.

Progress in Iron Ore Beneficiation. G. J. Holt. (Canadian Mining and Metallurgical Bulletin, 1950, vol. 43, Nov., pp. 636–638). The methods of iron ore beneficiation reviewed are chiefly those used for the concentration of ore from the Mesabi range in Minnesota. The deposits from this range

may be classified as follows : (1) High-grade ores, which may be shipped without concentration. (2) Straight-wash ores, from which coarse sand is removed by screening and fine sand by hydraulic means. The average recovery is 60% by weight. (3) Jig or heavy-media ores. These are treated in the same way as (2), but, in addition, intermediate sized rock is removed by jigs or heavy-media plant. The ferro-silicon heavy-media process has proved highly efficient, and gives a higher recovery (40–55%) than jig plants. (4) Taconites and Jaspers, which must be finely ground (65–200 mesh) to effect their liberation from silica, and then concentrated by flotation, roasting, and magnetic separation, or other methods under investigation. The finely ground concentrates are pelletized. For each type of ore, alternative methods of beneficiation are mentioned.—T. E. D.

Laboratory Studies on Iron Ore Sintering and Testing. F. M. Hamilton and H. F. Ameen. (Mining Engineering, 1950, vol. 187, Dec., pp. 1275–1282). Results of laboratory investigations of some sintering variables are presented. The effects on physical properties of mix component variations and rate of cooling of the sinter are illustrated by results of crushing and tumbler tests. Close control of fuel and moisture contents of sinter mixes is shown to be important. Effects of air cooling and water cooling are compared, and results of reducibility tests and microscopic examination of sinters are shown. The results of using solid additions in the mix in order to improve bed permeability are given. Sintering of pellets and other agglomerates was tried unsuccessfully.—E. C.

Bureau of Mines Studies Iron Ore Concentration—Gravity-Flotation Combination Appears Best. B. H. Clemmons. (Mining Engineering, 1950, vol. 187, Dec., pp. 1221–1224). The increasing necessity for utilizing low-grade iron ores, available cheaply in the Birmingham, Alabama, district, is stressed, and results of investigations on beneficiation by the Bureau of Mines are summarized. Reducing roasting by fluidization followed by magnetic separation is regarded as attractive, but a product of below 100 mesh grain size would have to be acceptable. Combined gravity and flotation methods are described as most promising. Thickening of slimes with 75% recirculation of mill water was possible, but thickening and filtration are regarded as the greatest problems involved.—E. C.

The Economics of Raw Material Supplies in the Birmingham District. E. C. Wright. (Mining Engineering, 1950, vol. 187, Dec., pp. 1214–1220). The author surveys trends in supply and cost of ore, coal, and coke for iron and steel making in the Birmingham, Alabama, district. Attention is paid to increased costs of mining, labour, and transport. Problems and possibilities of beneficiating local low-grade ores by various methods are considered and costs estimated. Prospects of importing foreign ores are surveyed. Based on these considerations, complete cost estimates for producing iron and steel are tabulated and discussed.—E. C.

Taconite : Iron Ore Bonanza. M. M. Hunt. (Steelways, 1951, vol. 7, Mar., pp. 1–5). The author gives an outline of the method used in the United States to utilize deposits of taconite, a low-grade iron-bearing rock. The ore is crushed, subjected to magnetic separation, and ball-milled. The iron concentrate is filtered off and balled up into pellets which are burned dry to give strength. Such pellets have been used in an experimental blast-furnace with complete success. It would appear that the technique is highly successful and gives hope of the utilization of similar deposits of ore in Labrador and Venezuela.—D. H.

Krupp-Renn Tests on French Minette Ore. P. E. Henry, C. F. Ramseyer, and J. R. Miller. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 66–78). A comprehensive description is given of the Krupp-Renn process, a method of recovering iron from low-grade siliceous iron ore under reducing conditions in a rotary kiln. Tests undertaken as the result of an agreement between the French Institut de Recherches de la Sidérurgie and the Czechoslovakian Steel Industry Administration are described, the various aspects of the process discussed, and its possible adaptation to American conditions considered. Detailed descriptions of the installations are given, including data on the kiln, charging, normal burden, slag composition, fuels, ball-milling before magnetic separation, and the products, consisting of three commercial grades of crushed slag and an iron concentrate in granules. Considerable operational and statistical information is given on the French ore tests, and the adaptation to American conditions is considered both from the technical and economic viewpoints.—M. D. J. B.

A Laboratory Wet Magnetic Separator for Strongly Magnetic Mineral Sands. W. R. B. Martin. (New Zealand Journal of Science and Technology, 1949, vol. 31, No. 3, Nov., pp. 5–21). A laboratory-size separator is described in sufficient detail to enable interested parties to reproduce it. Feed arrangements for both wet and dry sands are given. With a nominal through-put of 280 lb./hr. to give a commercial grade of concentrate, the separator is capable, at reduced capacity, of yielding an exceptionally high-grade uniform concentrate.—R. A. R.

The Low-Manganese Hessian Limonites and the Preparation of Lahn-Dill Ores. J. Dietrich. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1205–1208). The characteristics and extraction of Hessian basaltic limonite, Vogelsberg bauxite, and Mardorf ores are surveyed. The results obtained in dressing these ores with the Excelsior washing plant are described. The red hematite of the Lahn-Dill region is broken down and classified during beneficiation. The resultant ore is readily reducible and allows good furnace operation with low coke consumption.—J. P.

FUEL—PREPARATION, PROPERTIES, AND USES

Burner Behaviour on Unusual Gases. L. T. Minchin. (Coke and Gas, 1950, vol. 12, Nov., pp. 409–413 ; Dec., pp. 429–432). Methods by which the effects of gases of unusual composition on the behaviour of gas appliances may be predicted, are described and discussed. Four practical methods are given. (1) CHASO curves, in which cone height (CH) is plotted against air-shutter opening (ASO). These are simple to interpret, but as most burners are not as smooth as test burners, the tendency to light back may be greater than predicted. (2) Flame velocity curves, in which flame velocity is plotted against the air/gas ratio. Behaviour in a burner is affected by variations in the speed of propagation of a flame with the air/gas mixtures. (3) Combustion diagram (aerated burner), in which the co-ordinates used are air/gas against B.Th.U./min./unit of port area. Areas in which (*a*) burner flashes back, (*b*) flame blows off, (*c*) yellow tips appear, and (*d*) any other features occur can be noted and plotted. This method is most satisfactory. (4) Combustion diagram (luminous flame), in which the co-ordinates are pressure of supply and area of orifice. The defects which can be plotted are (*a*) extinction point, (*b*) lift point, (*c*) incipient lift point, and (*d*) roar point. A similar method is given for predicting the proportions of gas A and gas B that must be mixed for good combustion results. In addition, two interesting methods of forecasting behaviour from analyses alone, and one method in which limiting mixtures are calculated by a series of empirical modifications to the analysis are given, but the author believes that the only satisfactory methods are those in which laboratory tests are made on the gas mixtures in question.—T. E. D.

Radiation from Non-Luminous Gases. S. I. Evans. (British Coal Utilisation Research Association Monthly Bulletin, 1950, vol. 14, Oct., pp. 369–381). The author surveys the work done to date on this subject. At temperatures met in industrial practice radiation from non-luminous flames is due almost entirely to the CO_2 and water vapour in the hot products of combustion. After reviewing the present knowledge of the emissivity of CO_2 and water vapour, and mixtures of these two, a theoretical treatment of the subject is made.—B. G. B.

The Present Situation of Power Economy in the Generation of Steam and Electricity in Iron and Steel Works. K. E. Poppe. (Stahl und Eisen, 1950, vol. 70, Oct. 26, pp. 966–977). The energy balances of 14 iron and steel works during four separate months in 1948 and 1949 for the production of steam and electricity are set out in tabular form and then grouped according to size and type of plant. It is shown that modern high-pressure steam plants may consume less heat than big gas engines, but that the size and operating conditions of iron and steel works power equipment do not in general permit their installation. It appears that the introduction of gas turbines offers a way to improve power and heat economy, since they can achieve satisfactory efficiency in smaller units and are simpler to operate.—J. P.

Recuperative Furnaces. (Metallurgia, 1950, vol. 42, Sept., pp. 202–203). A short description is given of the uses to

which standard silicon carbide recuperator tubes may usefully be applied. Details are given of packings placed in the tubes to increase thermal efficiency. The layout of a soaking pit using this type of recuperator is given.—J. J.

Design of Regenerators for Gas-Turbine Service. D. Aronson. (Transactions of the American Society of Mechanical Engineers, 1950, vol. 72, Oct., pp. 967–978). The paper presents a method for designing gas-turbine regenerators with particular reference to the conditions of space being the principal limitations on design. For the plate-fin structure a procedure is given for arriving at maximum performance attainable in a given volume of regenerator core, and for calculating the fin patterns and plate spacings required to obtain such maximum performance. For the tubular-type regenerator a method of arriving at optimum tube spacings is presented.—D. H.

The Development of Coal Preparation in the Last Hundred Years. K. Thein. (Glückauf, 1950, vol. 86, Dec. 23, pp. 1225–1239). This review indicates that great developments in the period before the turn of the century formed the basis of the equipment and processes used now, whilst in the last ten years important supplementary processes have been introduced in all spheres. It is observed that advancement has been the result mainly of practical experience and science has not contributed much to improvements.—R. A. R.

Presentation of Cleaning Results. Belugou and Ulmo. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 14–23). The characteristics of the raw coal may be expressed by curves of washability as a function of density or ash content. Cleaning can be represented by : (*a*) Curves with washability of products plotted against the proportion of these products returned to the coal. From these, certain characteristic coefficients appear such as the yield by weight of washed middlings and slate ; and (*b*) partition curves having the form of a Gauss curve provided that in some cases $\log (d - d_o)$ is substituted for d as abscissa, where d_o is the density of the washing medium. The yield of a plant is best expressed by the ratio of practical to theoretical yield for perfect separation giving a washed coal of the same ash content. The inverse of this factor is proportional to the square of the probable deviation. For a plant giving three products the efficiency depends on the efficiency with which the high ash middlings are burnt.—A. G.

Theoretical Possibilities of Washing. Raineau and Belugou. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 24–41). The partition curve for a given apparatus can be predicted from data for similar plant. Collections of curves giving percentages of washed middlings, and dirt as a function of the efficiency of the apparatus expressed by 'imperfection,' and probable deviation have been made for about 20 French coals. Using these, the efficiency of a plant can be checked.—A. G.

Scientific Control of Washers. G. A. Vissac. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 42–51). The methods and principles employed and the unknowns concerned are discussed briefly. Two typical examples are given using data from the U.S. Bureau of Mines. Probable deviation is regarded as the most reliable and informative measure of efficiency provided that statistical principles are observed and all essential factors, *e.g.*, shape and size of grains, type of washer, partition density, characteristics of coal, are taken into account.—A. G.

Determination of the Precision of Separation in Coal Preparation Plant by the Calculation of Probabilities. A. Stratmann. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 52–59). For a given plant the relative errors of separation are independent of the coal used. In order to make a statistical study of the total imperfections contained in the partition curve and the curve of errors it is necessary to determine : (*a*) A mean fixing the position of the collection of errors, and (*b*) the amplitude of the spread of the collection of errors. By splitting up the composite curve of errors into several normal curves the causes of faults may be studied but further work on this is necessary. A detailed study of sedimentation in a fixed-sieve jig is given as an example.—A. G.

The Idea of Probability in Washing. Some Observations on the Error Frequency Curve. K. F. Tromp. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 60–74). The characteristics of the curve are discussed. When its abscissa is changed from $D_e - D$ to $(D_e - D)^{0.6}$ it is identical with the Gauss curve, this factor showing that it is the speed of fall or ascent which governs the probability of errors. The imperfection of washing depends on partition density, viscosity, and grain size and is greater for floats than sinks due to the differences in the time available for separation.—A. G.

Coal Preparation Plant in the United States. D. R. Mitchell. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 75–87). Installations have capacities up to 2000 tons of coal per hour and the types of coal and methods of control vary widely. The number and type of men needed to operate plants of different capacity are discussed. Data for report sheets are given with stress laid on the times and causes of stoppages. The technique of quality control by means of washability curves and such methods of expressing yield as Drakeley's equation, Hancock's graph of efficiency, and Tromp surface, are also considered.—A. G.

Statistical Methods Applicable to the Study and Control of Coal Preparation. A. G. Laurent. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Nov., pp. 88–103). Coal properties may be described by curves and functions provided the analytical form and parameter of these are known. In general these are found by statistical induction. The law of distribution enables properties to be expressed by a small number of characteristics and aids the comparison of different products. By representing the coal produced and the preparation process by statistical functions the distribution of the product can be deduced and hence one can control the operation or select plant to obtain a desired specification.—A. G.

Coal Sampling for Control Tests in a Dense Liquid. B. A. Landry and A. L. Bailey. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 131–143). It is difficult to obtain a representative sample since the coal must not be ground and can only be mixed by addition before subdivision. Results are given for the variance of laboratory samples after a complicated mixing process for four calibrations between two sieves of a Pennsylvanian bituminous coal. A method is described for establishing the variance found and the sampling characteristics of a coal in terms of its content of floats, middlings, and sinks.—A. G.

A New Development in Coal Sampling. J. Visman. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 144–155). With normal sampling the deviation between ash of samples and the mean ash of the product is between 1·5 and 5%. By automatic sampling taking between 30 and 1000 small samples, ash, sulphur, moisture, etc., can be calculated to within 0·5%. The precision can be calculated in advance and is regulated by number of samples, total weight of sample, and method of reduction.—A. G.

Methods of Judging the Working of a Plant for the Recovery of Slurries and the Clarification of Waters. J. A. Notary, H. B. Gorman, and T. Fraser. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 182–191). An accurate technique for the determination of the quantity of solids existing in the products is necessary after which a size analysis of the fine particles passing through all sieves must be made. To provide this information the firm of Heyl and Patterson (Pittsburgh) have developed a testing apparatus consisting of a small cyclone-type thickener, calibrated reservoirs to measure rates, and a pump to circulate samples of slurries. A complete separation of a slurry into five size groups takes 5 hr.—A. G.

The Microscope in the Service of Preparation. E. Nötzold. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 192–198). Microscopy gives information on the degree of scattering, the composition of bands and the nature of the impurities present in coal. The examination of polished specimens or thin sections by the ordinary microscope is slow, while for fine particles it lacks depth of focus. The development of the Stereokompolux microscope giving a stereoscopic image at magnifications up to 216 diameters is described.—A. G.

Control of the Washing of Fines in the Coal Basins. Belugou and Vitaux. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 209–229). Tests have been carried out on 20 fixed sieve

jigs, three flow washers, ten pneumatic cleaners, and three dense-liquid plants, yielding 290 partition curves. For fixed sieve jigs the probable deviation E was 0·04–0·37, the partition density d_p 1·3–2, and the imperfection $I = \frac{E}{d_p - 1}$ between 0·15 and 0·3 with a few exceptions. For a given jig the imperfection is constant.—A. G.

Clarification of Waters from Coal Washers and the Treatment of Fines by Flotation in Great Britain. J. L. Lewis. (International Conference on the Preparation of Coal: Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 262–292). Mechanization at the coal face and the use of water to cut down dust lead to a wetter coal with more fines. A widely applicable method for dealing with such material consists of wet sieving followed by dense liquid washing of the fraction above ¼ in. and froth flotation of the fines. Slurries may be treated by flocculation and details of advantages and costs are given.—A. G.

New Preparation Plant Features Modern Design and Equipment. W. S. Springer. (Mining Engineering, 1950, vol. 187, Dec., pp. 1249–1250B). A description of equipment, layout, and flow scheme is given of the coal beneficiation plant at the Concord mine near Birmingham, Alabama, producing coal for blast-furnace coke. Primary crushing and removal of tramp iron are carried out underground. The surface plant comprises crushing and screening equipment, large blending bins, a two-process washing plant, a water clarification and reclamation system, control laboratory, repair shop, and ancillary facilities.—E. C.

Economics of Coal Preparation. G. S. Jenkins. (National Association of Colliery Managers: Iron and Coal Trades Review, 1950, vol. 161, Dec. 1, pp. 825–829, 831). The author presents a general discussion of the economics of coal preparation, and draws particular attention to recent investigations which emphasize the necessity for adoption of anti-breakage measures to improve the product. He deals with hand-cleaning of large coal, mechanical cleaning, treatment of fines and size degradation, and considers the type of coal-preparation plant which should be installed. Finally, the economics of coal-preparation plant, from the viewpoint of period of operation, are dealt with.—G. F.

Carbonizing Properties: Pocahontas No. 6, Davey Sewell, and Fire Creek Coals from West Virginia and Upper and Lower Kittanning and Upper and Lower Freeport Coals from Pennsylvania. J. D. Davis, D. A. Reynolds, R. E. Brewer, D. E. Wolfson, B. W. Naugle, and G. W. Birge. (United States Bureau of Mines, 1950, Bulletin 496).

Coal Blending in the American Coking Industry. A. R. Powell and C. C. Russell. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 3–26). A review is made of the current state of commercial coal-blending practice in the U.S.A., also of some of the alternatives to blending which have been developed there, and some of the research projects that are being carried on. The objectives of coal blending are first discussed, these being the improvement of physical quality and uniformity of coke, control of carbonization pressures, control of yields of products, and utilization of inferior coking coals. The methods used for studying coal plasticity and carbonization pressure are then described. For the former, a modified Gieseler plastometer has been found to be the most useful apparatus, and for the latter a Russell or Koppers movable-wall oven is preferred. Some typical results obtained by these two methods are given. The authors survey American practice and research in coal blending, discussing the mixing of coking coals, coal and coke breeze, coal and anthracite fines, coal and low-temperature char, coal and pitch, and coal and oil, and the results obtained by these processes. The mechanics of coal blending, with regard to the blending of different coals of the same rank, and the blending of coal with coal of other ranks or other materials, and the equipment used are also discussed. They conclude with a review of the methods of obtaining desired objectives without blending, making special reference to the successful use of inferior coke in the blast-furnace, and to new methods for the control of carbonization pressures.—C. J. B. F.

Coal Preparation and Blending in the French Coking Industry and Present Practice and Research. J. L. Sabatier. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 27–34). A survey is made of the characteristic features of present French practice in coal preparation and blending for coking, and of the research work in progress. The first part of the survey deals particularly with practice at colliery coking plants, with brief mention of gasworks and steelworks coke-oven plants. The second part reviews the aims, nature, and results of research work in progress on the carbonization of Lorraine coals, with which present French research is mainly concerned. In particular, the techniques practised at the Carling coking plant, the Marienan experimental station, and the Thionville coking plant (where the Sovaco method is used), are summarized.—C. J. B. F.

Blending Work at the Fuel Research Station. A. Parker. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 35–37). Past and present work done by the Fuel Research Station on the blending of coals for coking is reviewed. The object of the work is to increase the range of coals that can be used for blending to give cokes with desired properties, including cokes for metallurgical purposes. Some typical results are given.—C. J. B. F.

The Blending Work of the British Coke Research Association. H. L. Riley. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 38–41). The author reviews four of the many aspects of the blending of coking slacks which are studied by the British Coke Research Association. These are: Coal supplies, the handling of coking slacks at the ovens, experimental oven tests, and the fundamentals of blending. It is found that the object of blending should be to control as far as is economically possible the following properties of a coking slack: Swelling number, agglutinating index, carbon/oxygen ratio, bulk density and size grading, ash composition (particularly with regard to sulphur), water content, and uniformity.—C. J. B. F.

The Work of the National Coal Board in Blending. W. Idris Jones. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 42–45). A review is made of the work of the National Coal Board on the blending of coals for coking. The main objects of the work have been: (*a*) To limit the use of Type 301 coals in Durham and elsewhere, by blending with other coals; (*b*) to promote the increased use of lower and higher rank coals, which are much more plentiful than first-class coking coals, and usually cheaper to mine; (*c*) to mitigate the dangerous swelling pressures which some South Wales coking coals develop; and (*d*) to study the mechanism of coking, with special reference to blending. Some of the results of this work are presented.—C. J. B. F.

The Rôle of the Test Oven in Blending Research. R. A. Mott. (British Coke Research Association, Fourth Conference, Oct. 25, 1950, pp. 46–47). The advantages of making tests in small-scale ovens, as compared with large-scale tests, are reviewed. In particular, the gain in using relatively small samples, thus enabling tests to be made on more expensive or rarer coals, is stressed. The small test oven may also be used to determine the optimum size of coal for carbonization, to give information on the effect of varying the rate of carbonizing, and, in conjunction with laboratory tests, to assess the coking values and blending values of coals.

Recent Developments in Gas Producers. G. W. C. Allan. (Journal of the Society of Glass Technology, 1950, vol. 34, Apr., pp. 40–54). Important requirements in the successful operation of gas producers are a deep fuel bed maintained in a uniform and compact condition and fuel of suitable and constant quality. Mechanical devices are discussed for maintaining uniformity of fuel (and ash) bed. The possibilities of the automatic control of gas producers in relation to the furnaces they supply and to delivering gas under pressure are discussed. Pitfalls in methods of gas analysis are commented on and recommendations are made. The chief requirements of the coal to be used are noted.—E. J. D. S.

TEMPERATURE MEASUREMENT AND CONTROL

Open Hearth Bath Temperature Measurement and Control. J. A. Creighton. (American Institute of Mining and Metallurgical Engineers, Open Hearth Proceedings, 1950, vol. 33, pp. 184–186: Journal of Metals, 1950, vol. 188, Aug., pp. 980–981). The author briefly describes the use of the platinum/platinum–rhodium thermocouple for routine bath temperature measurement and control at the Lackawanna Plant of Bethlehem Steel Co. Its use has enabled lower tapping temperatures to be adopted consistently, and is believed to have improved mould life, stool life, pouring practice, and steel quality. The total cost per reading is about $1.13.—G. F.

Optical Temperature Measurements on Luminous Flames. G. Naeser and W. Pepperhoff. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 9–14). Scattering of radiation by finely divided carbon particles produces a marked wavelength dependence of the absorptive power of luminous flames. True flame temperature can be determined from the colour and black-body temperature if absorptive power is taken into account. The dispersion of the absorption coefficients, which remains constant in the visible region, has been determined on several luminous flames. Within experimental error, the absorption coefficient of industrial flames is $\lambda^{-1\cdot2}$. Since the dispersion of the absorptive power depends, according to the optical theory of disperse systems, on the size of the carbon particles in the flame, the particle size of the soot has been determined. For industrial measurements with the Bioptix pyrometer, a diagram has been devised with the aid of which it is possible to convert directly colour and black-body temperature to true flame temperatures. The use of the diagram is illustrated by reference to some open-hearth flame measurements.—J. P.

REFRACTORY MATERIALS

Refractory Materials. L. Halm. (Métaux et Industries, 1950, No. 1, pp. 3–10; No. 2, pp. 39–49; No. 3, pp. 76–81). In the first part the author classifies refractories and describes the cone test and the determination of strength at high temperatures in the laboratory. The second part contains descriptions of the SiO_2–Al_2O_3 thermal transformation diagram and the phase-changes occurring in pure SiO_2, and illustrates these with micrographs of zones in a silica brick taken from an open-hearth furnace roof. The manufacture and properties of magnesite bricks are outlined; in spite of the high melting point of magnesia these bricks begin to yield at quite a moderate temperature because of the low viscosity of fused magnesia compared with fused silica. The final section deals with the applications of refractories in iron and steel works. (1) In blast-furnace stacks the requirements are resistance to abrasion and to deposition of carbon and ZnO, etc.; hence a brick of very low porosity is indicated. A brick fired at a high temperature, so that the iron oxides are slagged, resists carbon deposition better. (2) In Cowper stoves the bricks of the dome and top checkers should have a higher Al_2O_3 content than the rest. (3) In cupolas, where abrasion and slagging are very severe, a low Al_2O_3 brick will help to produce a more viscous slag, and so prolong its life. (4) In open-hearth furnaces, research is aimed at producing purer, and hence more refractory, silica bricks for the roofs. The end-walls may be chromite. (5) In ladles, thermal shock is a problem, and refractories should be high in Al_2O_3. The jointing material must be of the same material as the bricks themselves. The hole should be of softer material and the stopper hard (firebrick containing 16–20% graphite) to give a good seal. (6) For soaking-pit covers, an insulating material would have the additional advantage of being light. (7) In oil-fired furnaces the thermal and chemical actions are likely to be particularly severe: furnaces should be large enough to avoid having any flame impinging directly on brick.

N. McE.

Twenty-One Years Progress in Refractories. J. H. Chesters. (Metallurgia, 1950, vol. 42, Nov., pp. 293–296). Developments in refractories during the past 21 years are reviewed under the following headings: Raw materials; pretreatment; grinding and grading; mixing; moulding; drying; and firing. Improvements in the following refractories as a result of these developments are also given: Silica; dolomite; magnesite; chrome and chrome-magnesite; alumino-silicates; forsterite; and carbon.—J. B. B.

Carbon and Graphite as Constructional Materials. E. Franke. (Werkstoff und Korrosion, 1950, vol. 1, June–July, pp. 254–260). The production, properties, and applications of the different forms of carbon are reviewed, with 34 references (mainly 1946 to 1950) to the literature.—R. A. R.

The High-temperature Breakdown of Mullite and Other Alumino-Silicates in the Presence of Alkalis. G. M. Gad and L. R. Barrett. (Transactions of the British Ceramic Society, 1950, vol. 49, Nov., pp. 470–487). Mullite formed by heating mixtures of clay and natro-alunite had previously been found to decompose at 1250–1300° C. into corundum and glass under the influence of the alkali released. The present paper reports the investigation of the action of up to 4% Na_2O on pure mullites in the range 1150° to 1500° C. and on mullitic materials at 1400° C. By X-ray it was found that at 1400° C. the dissociation of mullite B (Al_2O_3 78%; SiO_2 22%) was probably diffusion controlled and was complete in rather more than 5 hr., whereas mullite A (Al_2O_3 71·8%; SiO_2 28·2%) was dissociated in 40 hr. although, according to the Na_2O–SiO_2–Al_2O_3 diagram, 88% of corundum crystals should have been in equilibrium with 12% unchanged mullite. Additional silica reduced the rate of attainment of equilibrium and free alumina increased it, as did increasing quantities of Na_2O. K_2O was less, and Li_2O more active; CaO and MgO were inactive.—E. J. D. S.

Some Trends in Iron and Steel Works' Refractories. G. R. Bashforth. (Refractories Journal, 1950, Dec., pp. 512–527). The author discusses the quality, choice, and performance of acid and basic refractories commonly used in present-day iron and steel works.—E. J. D. S.

Steel Ladle Refractories. J. I. Cordwell. (Refractories Journal, 1950, Oct., pp. 415–424; Nov., pp. 458–464). A general review of ladle refractories, their service conditions, and methods for testing them is given.—E. J. D. S.

Clay Graphite Brick for Ladle Refractories. E. B. Snyder. (American Institute of Mining and Metallurgical Engineers, 1950 Open Hearth Conference Proceedings, vol. 33, pp. 244–247: Journal of Metals, 1950, vol. 188, June, pp. 840–841). The author describes tests in which clay–graphite brick bands were used in the top section of ladles with the object of increasing ladle life. The bricks contained 15–20% graphite and were fired in a reducing atmosphere to prevent oxidation of the graphite. The bricks resisted high-oxide slags extremely well, in one case a 50% increase in ladle life being obtained, but their use in shops where high-oxide slags are common may be precluded by the violent reaction occurring between the slag and the graphite in the brick; this reaction, however, does not affect the steel analysis. A brick panel 2½–3 ft. high extending around one-half or three-quarters of the circumference is found to be as effective as a complete panel.—G. F.

Thermal Diffusivity of Refractory Oxides. E. S. Fitzsimmons. (Journal of the American Ceramic Society, 1950, vol. 33, Nov., pp. 327–332). Apparatus and method for measuring thermal diffusivity of refractory materials below 1000° C. are described. The difficulties of measuring quantity of heat are avoided by an experimental procedure based on transient heat conditions, requiring measurement of only the time interval and change in temperature. Samples of alumina, magnesia, zirconia, and alumina clay are reported on, and their variations of diffusivity with temperature are shown. Diffusivity is found to decrease with an increase in initial firing temperature. Results are compared with those of previous studies.—E. C.

Design and Performance of Electric Furnaces with Oxide Resistors. W. H. Davenport, S. S. Kistler, W. M. Wheildon, and O. J. Whittemore, jun. (Journal of the American Ceramic Society, 1950, vol. 33, Nov., pp. 333–339). Oxide heating elements for electric furnaces are described and discussed, also conditions for electric stability within an element or a group of elements. Problems of end-connections are considered. Several successful furnace designs are described, stabilized zirconia being used as heating elements. Two resistance furnaces operate in air at 1600° C., a hydrogen-atmosphere resistance furnace operates at 2200° C., and an induction furnace attains a similar temperature in air.—E. C.

A Quenching Furnace for High-Temperature Studies of Small Specimens. H. G. Sowman and A. I. Andrews. (Journal of the American Ceramic Society, 1950, vol. 33, Dec. 1, pp. 365–366). Details are given of construction and operation of a high-temperature quenching furnace for study of small specimens of refractories. A heavy tungsten wire coil or a tungsten tube are used as heat source. Operation is possible in vacuum, reducing, or neutral atmospheres. Temperatures of 2300° C. were attained during phase equilibrium studies of the system ZrO_2–TiO_2–SiO_2.—E. C.

Refractory Practice in the Whiting-Cole Recirculating Annealing Oven. R. A. Witschey. (Canadian Metals, 1950, vol. 13, Sept., pp. 26–27, 38). The author stresses the need for using suitable refractories and special constructional methods in order to attain better and shorter annealing cycles in Whiting-Cole recirculating periodic annealing furnaces. Details of refractory combinations are discussed, also progress in constructional methods. Outstanding features are flat suspended arch construction, and the use of a castable

insulating refractory for arch, lintels, and walls. Use of monolithic insulating refractory and positive anchorage permits provision of suitable expansion joints at all joining surfaces. E. C.

Contribution to the Identification of the Setting of Rammed Quartz Linings in Steel Furnaces. A. Palazzi and F. Savioli. (Metallurgia Italiana, 1950, vol. 42, Nov., pp. 410–417). Factors influencing the setting of pulverized quartzite and water mixes, used in the making of acid hearths, are discussed. The investigation establishes the procedure for obtaining optimum results with the raw materials available. Based on experimental data, hypotheses are put forward to explain setting. The preparation of raw materials, the types of quartzite, and mechanical and baking tests are described. The mechanical properties of linings are examined in relation to baking conditions. The authors conclude that the best type of quartzite is that normally used in the manufacture of glass, that mixes must be considerably worked, but not left standing for more than ten days, and that linings be laid as damp as possible and be allowed to retain their humidity. M. D. J. B.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Considerations Concerning the Extraction of Iron. R. Durrer. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Sept., pp. 171–173). This is a discussion, in general terms, of the history of the extraction of iron from its ores, and of the future modifications which will be necessary as a result of the exhaustion or replacement of the present raw materials. O. H. G.

The Blowing of a Blast-Furnace with High Top Pressure. P-M. André. (Revue de Métallurgie, Mémoires, 1950, vol. 47, Dec., pp. 873–888). After a review of the history of high top pressures and a discussion of relevant experimental work the effects on reactions, heat balance, flue dust, etc., are considered. The furnace modifications necessary amount to only 2% on the cost of a new furnace provided new blowing engines are not needed. Its adoption would benefit French practice with its poor ores, slow working, and frequent variations, and would give higher output and lower coke rates with less flue dust and channelling.—A. G.

Modern Blast-Furnace Installation. (Mechanical Handling, 1951, vol. 38, Feb., pp. 51–55). The redesigned equipment for the mechanical handling of raw materials at the blast-furnace plant of The Park Gate Iron and Steel Co., Ltd., Rotherham, is described.—D. H.

Blast Furnace Charging. (Electrical Review, 1951, vol. 148, Mar. 30, pp. 621–625). A description is given of the automatically controlled material handling and charging plant, for supplying two blast-furnaces, which was recently erected at the Rotherham works of the Park Gate Iron and Steel Co., Ltd. The modifications to the furnace tops, necessitated by the change-over from manual operation to mechanical handling with automatic electrical control, are also described. As a result of this reorganization, the two blast-furnaces were found to have a greater output of iron, together with a higher degree of efficiency.—C. J. B. F.

Contribution to the Metallurgy of the Blast-Furnace. T. Kootz and W. Oelsen. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 1–4). The processes in the blast-furnace are discussed on the basis of laboratory experiments on the reduction of iron and elements accompanying it. Particular attention is paid to the dissociation of CO and the effect of deposited carbon. The experiments and examples from blast-furnace operation make it appear that, after iron and phosphorus, silicon is reduced before the majority of the manganese and before desulphurization occurs. Further experiments demonstrated that the melting temperature of the burden controls the degree of reduction of the pig iron and that, under otherwise similar conditions, the reduction of accompanying elements and desulphurization proceed further with increased amounts of finely divided deposited carbon.—J. P.

The Electric Pig Iron Furnace. W. Wilke. (Demag News, 1951, Jan., pp. 7–14). The development of the electric pig-iron furnace is traced and the latest type is described. The furnace utilizes electrical heating in the form of an arc for providing and maintaining the required reaction temperature for the charge—a function performed by coke in the normal blast-furnace. The electrical system of the furnace is described and the type of electrode, lining, handling equipment, and charge composition is discussed. The special advantages of this type of furnace are given and it is stressed that it is only economical when electricity is cheap and plentiful.—D. H.

Norway Plans Electric Smelting of Pig Iron. B. M. Muller. (Canadian Metals, 1950, vol. 13, Sept., pp. 12–13, and 42–46). An integrated iron and steel plant under erection at Mo i Rana in Northern Norway is to operate four 20,000-kW. electric furnaces on locally available iron ore concentrates, either as sinter or as pellets. Various problems in planning the plant are pointed out. They concern the furnace type and size, power supply, ore preparation, sintering, coke handling, and smelting. General plant layout and materials handling are also considered. Estimated operational capacities and iron and steel output are quoted.—E. C.

PRODUCTION OF STEEL

Consett Iron Co., Ltd. (Chemistry and Industry, 1950, July 1, p. 498). Details are given of the extent and capacity of the company's works, which are completely integrated and include a large brickworks. Extensive improvements of, and additions to, the plant are being made.—N. McE.

Activities of the Creusot Works of Messrs. Schneider. (Engineer, 1951, vol. 191, Mar. 9, pp. 311–313). A description is given of the Schneider works together with a review of their historical development from Napoleonic times. The very severe damage done during the 1939–45 war is described together with the extensive reconstruction which has taken place in the last few years. Layout drawings of the works are given as well as illustrations showing the plant and products.—M. D. J. B.

The Clydebridge Steel Works of Colvilles Ltd. (Iron and Coal Trades Review, 1950, vol. 161, Oct. 20, pp. 581–584). The Clydebridge steelworks of Colvilles, Ltd., consists essentially of two melting shops, a slabbing mill, and a three-high plate mill, which, along with their auxiliary plant, are described in some detail. The principal product of the works is steel plates, the present total output being about 5000 tons per week of finished plates. The scheme of extensions now in hand is also indicated.—G. F.

Chile Starts Operation of Integrated Steel Mill. (Journal of Metals, 1950, vol. 188, Nov., p. 1316). A brief description is given of the new integrated steelworks at Huachipato, Chile, which started steel production in May 1950. The blast-furnace has an initial capacity of about 227,000 tons/annum, while the ingot capacity is estimated to be 260,000 tons/annum. G. F.

The D'Assailly Steel Works at Lorette (Loire). (Aciers Fins et Spéciaux Français, 1950, Nov., pp. 54–55). The history of D'Assailly works of the Compagnie des Forges et Aciéries de la Marine et d'Homecourt is summarized and a brief description of the present works is given. The products include tool, constructional, stainless and heat-resisting steels ; refractories ; and miscellaneous products such as hollow bars for mine drills, tie rods for boilers, spiral and coil springs, and spring washers.—E. C. S.

Developments in the Iron and Steel Industry During 1950. I. E. Madsen. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 109–140). This is a comprehensive review of economic and technical developments in the U.S.A. during 1950. A general economic survey of expansion estimates, prices, steel allocations, plant expansion, raw materials, and foreign developments is made. A detailed examination of blast-furnace and coke-plant developments is given together with a description of steelmaking and rolling mills. Finishing capacities are discussed in relation to United Nations demands. Fuels and furnaces, engineering developments, materials handling, and mechanical and electrical developments are also reviewed. Considerable statistical information is given together with numerous illustrations and a comprehensive table of electric motors of over 300 h.p.—M. D. J. B.

Manufacture and Properties of Low Nitrogen Bessemer Steels. I—Steelworks Tests. The Use of Limestone. P. Coheur. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 18–22). Additions of limestone, in sufficient quantities and at the correct time, have a de-nitriding effect independent of other attempts to lower the nitrogen content. Additions of 60 kg./ton lower

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the nitrogen by 30% and with an oxygen-enriched blast the steels are equal to those made in the open-hearth furnace. A. G.

Manufacture and Properties of Low Nitrogen Bessemer Steels. II—Steelworks Tests. Use of Steam–Oxygen Mixtures. J. Daubersy. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 23–30). Oxygen–steam mixtures may be safely used with reduced iron loss even when working with baths of high silicon content. The flame is clearer and the end of refining is shown by a distinctly paler colour. The nitrogen is lowered and desulphurization and dephosphorization are aided indirectly. Economic aspects are considered and the method is advocated for Bessemer refining of steels for cold working.—A. G.

Tests of Blowing a Bessemer Converter with Oxygen-Enriched Air. P. Leroy and E. Devernay. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 53–71; Feb., pp. 140–158). Trials are described aiming at a lowering of the nitrogen content and a study of such factors as the temperature; phosphorus and manganese content of the bath after blowing; the scorification of iron; and the yield of manganese from manganese additions. The effect of an enriched blast on the heat balance, blowing rate, and time of refining is discussed and the calorific equivalents of nitrogen-scrap additions and scrap-oxidizing additions are calculated. Optimum results are obtained with 30% of oxygen.—A. G.

Application of Metallurgical Knowledge to Steelmaking. H. Müller. (Die Technik, 1950, vol. 5, Aug., pp. 412–418). The author considers in what way the productivity of the steel industry of the East German Republic may be increased during the coming five-year plan. He discusses the fundamental differences between basic-Bessemer and open-hearth steels and refers to the dephosphorization of the former by the Perrin method, and considers the problems arising out of the shortage of suitable raw materials, particularly of phosphorus-rich ores, of pig, etc. He recommends higher working temperatures.—J. G. W.

Transformation of Pig Iron into Steel in the Converter Using Pure Oxygen. H. Hellbrügge. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1208–1211). The investigations at the L. von Rollschen Eisenwerke, Gerlafingen, Switzerland, on a 2·5-ton side-blown converter with a water-cooled tuyere are described. It is claimed that the refining of pig irons of the most varied composition can be carried out with pure oxygen. There were no difficulties due to wear of the tuyeres or the lining of the converter and the narrow composition limits usually necessary for basic or acid blowing need not be observed. The amount of scrap which can be melted depends on the composition of the pig iron, being about 40% with ordinary basic or acid-Bessemer iron. The finished steel has a nitrogen content of approximately 0·006% and its quality corresponds with that of normal open-hearth steel. J. P.

Process for Improving Basic-Bessemer Steel. E. Warnant. (Stahl und Eisen, 1950, vol. 70, Nov. 9, pp. 1077–1079). An investigation in Belgium designed to produce low-nitrogen Bessemer steel is summarized. The investigations were in three parts. The first part concerned the influence of iron composition, temperature, composition of the blast, etc., on the nitrogen content of the blown steel. In the second part, iron was heated in an arc furnace and blown with various mixtures of oxygen and CO_2 or oxygen and steam. These tests showed that it was possible to produce a finished steel with $P < 0{\cdot}03\%$ and $N < 0{\cdot}003\%$, which had superior qualities when fabricated. The third part showed that the methods could be applied to normal converters without any trouble and gave essentially the same results. The Warnant process employs lime and ore additions and oxygen-enriched air for preliminary blowing and finishes off with a mixture of oxygen and CO_2 and can produce low-nitrogen steel consistently. A typical crude iron (0·9% Mn, 0·5% Si, 2·1–2·2% P, 0·04% S, 0·017–0·009% N) can be blown in 9–9½ min. to a composition 0·06% C, 0·3–0·5% Mn, 0·04–0·05% P, 0·033–0·035% S, and 0·0007–0·0015% N_2. The low nitrogen content overcomes the effect of the slightly high phosphorus, and the steel, when rolled, is of great ductility and resistant to age-hardening.—J. P.

Study of Fuel Gas Flow in the Open-Hearth Furnace Using Models. F. Schultz-Grunow. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1211–1213). The results obtained in experiments with a glass model furnace using air or water and a lighted section technique are illustrated. The usefulness and simplicity of such models for assessing effects of changes in port design on furnace efficiency and refractory wear are stressed.—J. P.

Flow Patterns in the Open-Hearth Furnace in the Light of British Model Experiments. M. Hansen. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1213–1219). The results of British experimental work in this field, as reported in Journ. I. and S.I., 1949, vol. 162, Aug., pp. 385–415, are reviewed.—J. P.

Control Methods used in French Open-Hearth Plants. G. Husson and P. Rodicq. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, Dec., pp. 937–946). Methods employed at the Creusot, Hagondage, Longivy, and Micheville works are described. To regulate melting, the number of variables should be limited and the suggested system of control is (*a*) manual control of the combustion gas guided by a roof temperature indicator, and (*b*) automatic regulation of air in relation to gas in a ratio previously chosen by the smelter.—A. G.

The Activity of Sulphur in Liquid Steel : The Influence of Copper. T. Rosenqvist and E. M. Cox. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1389–1393; Journal of Metals, 1950, Nov.). Results are given of an investigation into the influence of copper on the activity of sulphur in liquid steel, in which melts of various sulphur and copper contents were brought into equilibrium with a H_2S–H_2 gas mixture. It is shown that the presence of small amounts of copper have no significant effect on sulphur activity in the steel bath, or on the desulphurization process, as there is no appreciable decrease in the activity unless the sulphur content exceeds about 0·5%. A structural model for the iron–copper–sulphur melt is also suggested.—G. F.

Oxygen for Carbon Reduction and Temperature Pickup. E. H. Reyer. (Journal of Metals, 1950, vol. 188, Aug., pp. 982–983). The author briefly describes the use of the oxygen lance on 170-ton open-hearth furnaces at Keystone Steel and Wire Co., Illinois. The practice is adopted as standard when extra production is required, and increases the production rate per furnace from about 11½ to 14–15 tons/hr. The injection rate is about 450 cu. ft./min., the average direct cost of lancing being about 28 cents/ton.—G. F.

The Use of Oxygen in the Basic Open-Hearth Furnace. J. Natkaniec. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 47–53). [In Polish]. Advantages and disadvantages of the use of oxygen in the open-hearth furnace are discussed, and the results of the authors' experiments conducted with a 36-ton furnace showed an increase in furnace output of 15·4%, the reduction in refining time of 13·4%, a decrease in consumption of ore of 58·7% and of fuel by 17·3%. Very satisfactory results were obtained from five heats in which oxygen was also used for melting scrap. The time of the process was reduced by 43·8% and furnace output increased by 77·8%.—V. G.

Flow and Velocities of Air and Waste Gases in Open Hearth Furnaces. H. V. Flagg. (American Institute of Mining and Metallurgical Engineers, Open Hearth Proceedings, 1950, vol. 33, pp. 253–267 : Journal of Metals, 1950, vol. 188, Aug., pp. 976–979). The author briefly discusses the effect of certain critical areas, particularly the cross-sectional area at the 'knuckle,' on the flow and velocity of air and waste gases in the open-hearth furnace system. Emphasis is placed on the incoming gas and air systems, and the conditions of flow and velocity in gas-fired and oil-fired furnaces are compared. G. F.

Pressure and Flow Distribution in a Venturi-Type Open-Hearth Furnace : Model Employed in Experimental Investigation. J. A. Leys. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 22, pp. 971–975). The author describes the use of a $\frac{1}{24}$ scale model of a 120-ton Venturi furnace, with air as working fluid, in an investigation of pressure losses and flow distribution in the uptakes, and in a velocity survey in the furnace chamber. The results show an asymmetry in incoming air flow and outgoing waste-gas flow, with an excess on the stage side, but it is suggested that this will have no pronounced effect on flame direction, particularly in a Venturi furnace with its pronounced 'knuckle.' The results on pressure losses have confirmed existing data, and may be applied directly to existing furnaces. The theoretical grounds on which the behaviour of the model is related to that of a production furnace are discussed in an appendix.—G. F.

State of Practical and Scientific Knowledge of Metallurgical Quality Control of Steel. E. Maurer. (Die Technik, 1950, vol. 5, Oct., pp. 499–513). In a comprehensive review the author deals with all principal topics of steelmaking. In each case he first outlines the present state of knowledge, drawing on American literature and his own hitherto unpublished findings, and then remarks generally on the application to steelmaking practice and concludes by surveying the practice prevailing in the steel industry of the East German State. The topics are: Desulphurization of basic pig by sodium carbonate; comparison of West and East German dolomites; behaviour of sulphur in the open-hearth process; behaviour of phosphorus and nitrogen in the open-hearth and basic converter processes; behaviour of phosphorus; and dephosphorization with reference to the law of mass action. J. G. W.

Slag and Removal of Elements in the Basic-Open Hearth Process. Part II—Phosphorus. E. Bucko. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 4, pp. 309–325). [In Polish]. On the basis of statistical analyses the influence of individual factors on phosphorus removal and the velocity of this process is considered. From the results obtained in practice the equilibrium constant k_2 was calculated from the formula

$$k_2 = \frac{(P_2O_5)}{[P] \times (FeO)^5}$$

From the diagrams the relation between k_2, the lime in the slag, and its basicity (CaO/SiO_2) were determined. The relation between the ratio $(P_2O_5)/[P]$, the phosphorus in the metal bath, and the slag basicity is discussed. The influence of the iron in the slag on phosphorus removal was investigated. The reduction to phosphorus of P_2O_5 in the slag is examined. V. G.

Slag Control in Open-Hearth Furnace. K. Radzwicki and K. Fiolkowna. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 1–97). [In Polish]. The introduction and wide application of the pancake method of slag control met with some difficulties due to the crumbling of slag samples and to photographs not showing the main characteristics of the patterns clearly enough. Other methods such as conductometric, potentiometric, and volumetric titrations of aqueous extracts of slag are compared, and their suitability for evaluation of slag basicity discussed. A volumetric titration method using 0·1 *N* sulphuric acid was proposed as being accurate enough and easy to apply in steelworks laboratories.—V. G.

The Control of Steel Quality. G. R. Bashforth. (British Steelmaker, 1951, vol. 17, Feb., pp. 89–97). The author first surveys the defects which are commonly experienced in steel production and treatment, and suggests methods for the reduction or prevention of these imperfections. He then outlines the principal features which should be noted in order to ensure a high standard of quality control, dealing briefly with steelmaking practice, casting-pit practice, and ingot heating and rolling. A diagrammatic representation of the general principles of quality control is included.—G. F.

Statistical Analysis of Open Hearth Data. W. R. Weaver. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 53–57). Attention is drawn to the usefulness of keeping records in the open-hearth shop and to the results which may be obtained by statistical analysis. Charts are given showing the distribution of scrap-charging time, the frequency distribution of the sizes of heats tapped from furnaces of identical size making the same grades of steel, and the pouring temperatures of individual heats. Methods of setting out, plotting, and analysing simple statistical data are given, leading to the substitution of fact for opinion, the establishment of points of reference, and a better knowledge of the problems involved in the open-hearth process.—M. D. J. B.

Operating Advantages and Limitations of Open Hearth Controls. B. B. Bargman. (Iron and Steel Engineer, 1951, vol. 23, Mar., pp. 91–95). The author reviews the advantages and limitations of existing instrumentation and control of open-hearth operations. The measurement and control of fuel which serves as a basis of cost allotment is discussed together with the measurement and control of air, steam, and furnace pressure. The methods developed to determine when a furnace should be reversed are also discussed. Lastly, the author considers roof temperature limit control to prevent overheating of the roof, and thermocouples and radiation units to assess bath temperature.—M. D. J. B.

The Chemical and Physicochemical Basis of Deoxidation with Manganese, Silicon and Aluminium. W. Koch, H. Wentrup, and O. Reif. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 15–30). The inclusions, formed in casts made from Armco iron deoxidized with various amounts of alloys containing manganese, silicon, and aluminium in varying proportions, have been isolated by the Klinger-Koch procedure and examined chemically, microscopically, and by X-ray diffraction. The investigation showed that the composition of the inclusions was not in equilibrium with the final composition of the melt but was determined by the course of the deoxidation reaction. If liquid silicates are formed immediately after the addition of the deoxidizer, these can be reduced by manganese or aluminium in the melt, and in taking up silica or alumina become viscous, glassy, or solid. The reaction of these viscous or solid particles with the melt is very slow and is not complete when the cast has solidified. The liquid inclusions rise very rapidly through the melt and, depending on ingot height, often rise to the surface before they have undergone further appreciable reaction. Deoxidizing alloys containing silicon, aluminium, and manganese readily form viscous siliceous inclusions with high manganese and aluminium contents if the Mn/Si ratio in the alloy is less than 2. With higher Mn/Si ratios, solid crystalline inclusions with high alumina contents are formed. Since the siliceous inclusions do not rise readily in the melt, the oxygen content of the cast is high.—J. P.

The Deoxidation of Steel with Synthetic Acid Slags. M. Paschke and G. Gesche. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 5–8). Experiments have shown that the silica content and the viscosity play the most important parts in the deoxidation of steel by acid slags ($CaO/SiO_2 = 0$–$0·8$). Increasing silica content favours deoxidation since it reduces the activity of FeO but it increases the viscosity and so makes reaction more sluggish. Alumina has no chemical effect on the deoxidizing power of slags; it acts as a diluent and increases viscosity. Deoxidation is more complete in a sand than in an alumina crucible because of the availability of silica.—J. P.

Economics of a 500-Ton Open Hearth Furnace. W. W. Kompart. (Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 55–57). **550 Ton Open Hearth Shows Operating Economies.** W. W. Kompart. (Steel, 1950, vol. 127, Oct. 23, pp. 78–80). The author briefly discusses the advantages of very large open-hearth furnaces and gives the constructional features of a stationary 500-ton furnace. Details are given of the steelwork, brickwork, overall general dimensions as well as of the operating features, hot metal analysis, and type of scrap charged. It is claimed that the furnace has reduced rebuilding costs by 25% per ton of steel produced. Fuel consumption is also discussed. No advantages are claimed for the use of oxygen enrichment to melt down scrap, but oxygen is used in the bath to cut down tap to tap time. M. D. J. B.

Stud Welded Open Hearth Doors Minimize Production Losses. R. C. Singleton. (Steel, 1950, vol. 127, Oct. 16, pp. 134–144). Open-hearth furnace doors rammed with a plastic chrome ore, keyed on to rows of welded studs are claimed to provide cheaper operation than a bricked door. A certain amount of care is required in the initial layout of studs, which provide additional cooling by heat conduction to the back of the door, and in relining. A detailed cost comparison of the two types of door is made and it is shown that the five to seven times greater cost in lining is offset, amongst other factors, by a life about ten times as long.—A. M. F.

The Steel Melting Practice Adopted at Iscor Works, Pretoria. C. P. Warden. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1950, vol. 51, Nov., pp. 177–197). The acid-Bessemer and basic open-hearth processes used at this plant are discussed in general terms. Details are given of the duplex process by which steel is mainly produced at Pretoria. The effect of duplexing on the rate of furnace production is shown by graphs and considered. Particulars of typical charges for a structural steel and a rail steel are given.—R. A. R.

Mineralogical Investigations of Basic Open-Hearth Slag. J. Zieba. (Hutnik, 1950, vol. 17, Nov.–Dec., pp. 410–415). [In Polish]. Mineralogical investigations of basic open-hearth slags (basicity 1·55 to 3·61) by optical methods are described. V. G.

The Use of Oxygen in Electric Arc Furnaces. M. Hauck and H. Werwach. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 15–18). The experiences at the Stahlwerke Bochum A.G. in the use of oxygen lancing in the melting and refining of steel in a 9½-ton Stein-Roubaix arc furnace are reported. The quality of the steel produced was equal to that without the use of oxygen. A 30–40% increase in hourly output, a 20–25% reduction in current and the saving on ore, fluorspar, lime, and electrodes resulted in reduced costs as compared with normal operation. The loss of chromium in refining chromium–nickel and chrómium–manganese steels was 3–4 kg. per ton less than usual. Initial difficulties with regard to the life of the hearth and cover have been overcome.—J. P.

The Use of Pure Oxygen in the Refining of Stainless Chromium–Nickel Steels. F. Illian. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 18–19). The work at the Deutsche Edelstahlwerke A.G., Krefeld, on the production of 18/8 type stainless steel in 8- and 10-ton arc furnaces is reported. Steel quality was as good as normal and under suitable conditions the use of oxygen lancing results in saving of electrodes and current. Sintered magnesite proved to be the most satisfactory material for the hearth. When the charge consists of 100% chromium–nickel steel scrap, it is possible to refine down to a carbon content of 0·05% and to avoid all loss of nickel. The relationship between final chromium and carbon contents and temperature of the melt is discussed and a curve is presented showing the chromium loss as a function of the final carbon content. This indicates that reduction of carbon to very low values is associated with heavier losses of chromium. Some preliminary results in refining plain and low alloy tool steels are briefly reported.—J. P.

Inductive Stirring in Arc Furnaces. L. Dreyfus and F. Nilsson. (Stahl und Eisen, 1951, vol. 71, Feb. 1, pp. 133–141). This is an account in German of the theory and practice of the inductive stirrer which has been applied to electric arc furnaces in Sweden (*see* Journ. I. and S.I., 1950, vol. 166, Sept., p. 94).—R. A. R.

Oxygen in the Production of Carbon Steels from the Arc Furnace. A. C. Brearley. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Mar. 22, pp. 303–309; Iron and Coal Trades Review, 1951, vol. 162, Mar. 30, pp. 739–745). The early disappointing results of using the oxygen lance in an effort to increase the melting speeds of a 5-ton basic, and a 4½-ton acid electric furnace at the works of K. and L. Steelfounders, Ltd., are described. A great improvement was obtained, however, largely as a result of a visit to America. Present practices for both furnaces are described in detail. Features are: The entire elimination of ore; the use of a ½-in. dia. lance, protected by a ½-in. layer of aluminous fireclay cement; the immersion of the lance 4 to 6 in. into the bath; an oxygen pressure of 90 lb./sq. in.; and a flow rate of 200 cu. ft./min. A drawback, relating to the basic furnace, is that the final phosphorus content tends to be 0·005% higher than when ore was used. The economics of the ore and the oxygen processes are compared for both furnaces. The principal findings are summarized as: (1) Time savings average 30 min. a heat on the acid furnace and 15 min. on the basic. (2) Neglecting any savings due to increased output, economies of about 7*s.*/ton of liquid steel on the acid and 2*s.*/ton on the basic furnace are being secured. (3) No increased refractory wear in either furnace is discernible. (4) There has been no deterioration in the quality of the steel produced. (5) The use of iron ore has been entirely eliminated. (6) Expensive hold-ups due to high carbon melts have also been eliminated.—J. E. W.

The Effect of Design and Size of Ingot Moulds on Their Life. K. Radzwicki. (Prace Badawcze Glownego Instytuto Metalurgii i Odlewnictwa, 1950, No. 4, pp. 285–308). [In Polish]. The effect of individual design factors on the life of ingot moulds and on the steel solidification process is described. The design and life of ingot moulds used in Polish steel plants are analysed.—V. G.

Horizontal Continuous Casting Machine. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 144–147). This article describes a new development in continuous casting recently patented by J. F. Jacquet, technical secretary of the Belgian Blast Furnace and Steel Works Association. The method produces small cross-section steel ingots which can be rolled directly by the finishing mills. The rapid cooling of ingots gives a fine and uniform crystalline structure; the method eliminates piping, reduces cracks and scratches on the ingot skin, and achieves the mechanization of the ingot-casting operation. The moulds are directly connected to the ladle and the ingots are cast in the horizontal position. The advantages claimed for the method are described and the main technical details outlined.—M. D. J. B.

Ten-Ton Ingot Moulds—A Comparison of Design and Conditions of Use. A. Jackson. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 289–301). The design and life of two types of ten-ton mould and bottom plate are compared under normal conditions of use, and, for the later type, the results of detailed experiments, designed to indicate the effect of certain variables in the conditions of use, are shown. Both types produce the same ingot size, but the mould design was later modified and improved by alterations based on the failings of the earlier design. The effects of short and long tap-to-strip times and normal and long cooling times between heats are evaluated. The various types of failure are discussed and conclusions indicate the possibility of very high mould lives being achieved, provided stripping is sufficiently rapid. Experiments are described on the heating and cooling rates of moulds, the effects of annealing on mould life, and the effect of order of manufacture, and other miscellaneous data.

Ingot Heat Conservation—Ingot Mould Temperature Measurements. R. T. Fowler and J. Stringer. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 283–288). Further measurements on the surface temperatures of an ingot mould have been made, and the technique of temperature measurement by fixed thermocouples has been extended to include temperatures through the walls. Two trials were made with the mould initially at a temperature of 30° C., and one trial with the mould at 125° C., the latter being representative of normal practice. Temperature gradients and isotherms have been plotted to give a picture of the overall temperature distribution throughout the mould at various times from teeming. From the results obtained, the heat content of the mould was calculated and the amount of heat removed from the steel during solidification was estimated.

Non-Metallic Inclusions in Acid Open-Hearth Steel. A. Carlini. (Metallurgia Italiana, 1950, vol. 42, Dec., pp. 435–456). A qualitative and quantitative examination is made of non-metallic inclusions in cast and forged steels. A number of graphs are given showing the mechanical properties of the steel in relation to its characteristics, the number of inclusions, the nature and magnitude of the inclusions, and the variable factors arising in steelmaking. The investigation covers tests carried out on over 500 casts and the analyses of inclusions have been made on samples taken from 78 of these. Details are given of the experimental technique including sample preparation, microscopical examination, acid testing, and heat-treatment. A classification of inclusions is given with many microphotographs. There are 26 references.—M. D. J. B.

PRODUCTION OF FERRO-ALLOYS

Ferrochromium from Low Grade Chromite Ores and Concentrates. F. W. Wessel and R. T. C. Rasmussen. (Journal of Metals, 1950, vol. 188, Aug., pp. 984–988). The authors describe tests made on concentrates of the low-grade Mouat chromite ores, in which the chromium/iron ratio is about 1·4/1, with the purpose of studying the smelting characteristics and determining whether a sufficiently high-grade ferrochromium could be produced from this type of ore by usual electric furnace smelting procedure. Single-stage batch smelting on a magnesite hearth produced ferrochromium containing 49·1% Cr, 37·3% Fe, 4·0% Si, and 6·5% C. It is concluded that continuous open-top electric smelting of Mouat chromite concentrate is feasible, and that smelting on a silica hearth would produce ferrochromium with a considerably higher chromium/iron ratio than that of the chromite concentrate. A high-silicon, low-carbon crude metal should be aimed at for subsequent refining to low-carbon ferrochromium.—G. F.

FOUNDRY PRACTICE

Production and Methods Control. T. H. Wood. (Foundry Trade Journal, 1950, vol. 89, Dec. 21, pp. 529–533). General applications of a production control system applicable to almost any foundry, large or small, are presented. The necessary paper work and the operation of suitable board

controllers are detailed, and reference is made to the flow chart and its co-ordination with operating methods and final completion.—J. E. W.

Notes on the Design of Castings. (Power and Works Engineering, 1950, vol. 45, Sept., pp. 319–320). Advice on the designing and ordering of ' one off ' castings occasionally required by the works engineer is given. It is stressed that the foundryman should be consulted and given exact details of the purpose to which the casting is to be put.—A. M. F.

" Esse " Foundry Mechanisation Scheme. A. R. Parkes. (Foundry Trade Journal, 1951, vol. 90, Feb. 8, pp. 141–149). The new mechanized foundry of Smith and Wellstood, Ltd., gave an immediate production of 63 tons per week, and will produce 120 tons a week when completed. The relatively uncongested floor has an area of 48,000 sq. ft., and the foundry has a personnel of 90. The melting, pouring and knock out, sand plant and treatment, heavy and light moulding sections, and dust and fume extraction plant, are fully explained.—J. E. W.

Castings for Machine Tools. A. G. Thomson. (Foundry Trade Journal, 1951, vol. 90, Jan. 25, pp. 101–104). Technaloy, Ltd., a subsidiary of Murad Developments, Ltd., supply the parent company with castings for machine tools. Built in 1947, the 22,000-sq. ft. floor area accommodates the iron and non-ferrous foundries, pattern and core shops, fettling shop, and changing rooms. Features of the new foundry are ducts leading to underground conveyors which carry tipped sand to the sand treatment unit, interior situation of the cupola charging platform, the close proximity of the chemical laboratory, and the unloading of sand from lorries directly into their appropriate bins through shutters provided in the wall. Production is expected to rise from 10–12 to 50–60 tons of castings per week when all developments have been completed.—J. E. W.

Modern Foundry in an Old-World Setting. A. G. Thomson. (Foundry Trade Journal, 1951, vol. 90, Jan. 4, pp. 13–16). The Western Foundries, pleasantly situated in Southall, Middlesex, consist of an iron foundry, small non-ferrous and light alloy foundries, a pattern shop and temporary pattern store, and large machine shops. The main products are castings for pumping units for oil wells, castings for milk bottle machinery, bottle-washing equipment, water filtration pumps, machine tools and dies, and components for heating stoves, ranging in weight from a few ounces to 4½ tons. The output is 2000 tons annually, produced by a staff of 65 to 70. To deal with this production the foundry has been rebuilt to modern design.—J. E. W.

Effect of Oxygen Content on Iron Casting Properties. F. S. Kleeman. (Foundry, 1951, vol. 79, Jan., pp. 100–103, 237–241). Investigations, carried out by numerous workers, which have thrown light on the problem of the spasmodic production of batches of defective iron castings are reviewed. The main cause, traced to the presence of dissolved oxygen, is discussed; the use of silicon carbide is also dealt with. It is claimed that the refractoriness of this carbide facilitates prolonged contact between carbide and molten iron in the cupola. Chemical analysis and the colour of the cupola slag give a measure of the deoxidation in the cupola. The greater the amount of FeO in the slags the more material requires to be re-annealed. The reduction of segregation and the importance of machinability resulting from deoxidation are also discussed.—E. J. D. S.

Jigs and Fixtures for the Foundry. T. A. Dickinson. (Foundry, 1950, vol. 78, Oct., pp. 200–206). The application of jigs and fixtures to various foundry operations is discussed. The general technique is illustrated by reference to pattern making and handling, and the removal of fins from sand cores. Brief mention is made of the sealing and testing of castings.—E. J. D. S.

International Harvester Co. Dedicates New Research Foundry. (Foundry, 1950, vol. 78, Oct., pp. 114, 169, 171–172). The purpose, projects, and layout of a new research foundry are outlined.—E. J. D. S.

Controlling the Production of Grey Cast Iron. B. Tyberg. (Gjuteriet, 1949, vol. 39, No. 6, pp. 85–91). [In Swedish]. A number of testing and controlling procedures for cupola blast, pig iron, scrap, coke, limestone, and cast iron have been compiled. The applications of spectrographic methods are limited. The standard strength tests and the Ludwik-Krystof shearing test are described.—B. S. E.

Economic Comparisons between Cupola and High-Frequency Furnace for Melting Grey Cast Iron. E. Dalne. (Gjuteriet, 1949, vol. 39, No. 8, pp. 126–130). [In Swedish]. Studies made at the foundries of ASEA (The Swedish General Electric Co., Ltd.) show that in spite of higher initial cost a high-frequency furnace is more economical than a cupola provided that cheap scrap is available.—B. S. E.

Some Examples of British Cupola Control. L. Lange. (Gjuteriet, 1949, vol. 39, No. 9, pp. 143–146). [In Swedish]. The author describes a visit to the Idoson Motor Cylinder Co., giving details of the ' Pari-Blast ' cupola and the chill test employed there, and discusses the instrumentation for air control.—B. S. E.

Calculating the Charge for the Cupola. C.-G. Nilsson. (Gjuteriet, 1949, vol. 39, No. 12, pp. 189–192). [In Swedish]. The author gives examples of a method for calculating charges for a 44-in. cupola, using the analytical relationships of charge to melt for each component as correction factors. B. S. E.

On the Use of Fluorspar in Cupola Furnaces. R. Frey. (Brennstoff, Wärme, Kraft, 1950, vol. 2, Nov., p. 344). The author advocates the use of fluorspar in cupola furnaces as fluxing agent in preference to lime, the former being more economical in spite of higher cost. This is due to a considerable reduction in coke consumption as compared with lime, increased life of refractory linings, and reduction in melting time with consequently increased productivity. Comparative experimental data are quoted.—E. C.

A Review of the Developments in the Metallurgy of Cast Iron. J. E. Hurst. (Metallurgia, 1950, vol. 42, Nov., pp. 289–292). Developments in the metallurgy of cast iron during the last 21 years are reviewed under the following headings : Nodular cast irons ; gaseous annealing processes for the production of malleable cast iron ; high-duty cast iron ; martensitic irons ; high chromium irons ; acicular irons ; heat-resisting irons ; and corrosion-resisting irons.—J. B. B.

Spheroidization of Eutectoidal Cementite in White Iron. J. Piaskowski. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 4, pp. 269–272). [In Polish]. The author presented a theory according to which the accelerated process of cementite spheroidization occurs in hypereutectic iron–carbon alloys because of the formation of spheroidization nuclei at temperatures above the critical point. During the cooling within critical temperature range the cementite of the eutectic mixture, formed from the decomposition of the austenite, crystallizes on those nuclei. The spheroidization of cementite in white iron causes an increase in the tensile strength from 30 to 50–60 kg./sq. mm., the elongation may rise to 1·5%, the impact strength to 1·5–1·8 kg./sq. cm., but Brinell hardness falls from 380–420 to 380–320 depending on the cooling rate.—V. G.

Nodular Iron Experiments. E. M. Stein. (Foundry, 1950, vol. 75, Nov., pp. 96–99, 214, 216–220). Two base irons containing approximately 3·30% C and 3·55% C, and 1·8% Si and 1·6% Si respectively, each with 0·65% Mn, 0·14% S, 0·14% P, 0·2% Cu, 0·10% Ni, 0·10% Cr, and 0·10% Mo, were melted in a cupola and nodulized. Apart from inoculation additions, the nodulizing alloys used were 50/50 Ni–Mg, which failed to take effect and reacted violently in the ladle, 80/20 Cu–Mg, and 70/30 Cu–Mg which also failed to produce nodular graphite, 34/7 and 43/9 Si–Mg which gave inconsistent results, and 80/20 Ni–Mg alloy which produced generally consistent results. The latter alloy was also used to nodulize charcoal pig iron melted in an acid electric furnace. With 80/20 Ni–Mg alloy the cupola iron had a predominantly pearlitic matrix as cast, whilst the electric furnace nodular iron was mainly ferritic as cast. For the pearlitic iron a tensile strength of 80,000 to 100,000 lb./sq. in. and an elongation of 1 to 3% were consistently obtained, and it is considered that this elongation could be improved with a controlled cooling rate. Using 80/20 Ni–Mg alloy, as-cast electric furnace irons had a tensile strength of 74,800–83,000 lb./sq. in. and 13–18% elongation. After holding at 1350° F. for 2 hr. the tensile range was 68,600 to 77,700 lb./sq. in. and the elongation had increased to 16–22%. The electric furnace iron showed a dark grey fracture, although no flake graphite was observed. The greyness appeared to be related to elongation.—E. J. D. S.

Malleable Cast Iron in the United States. J. V. Bairiot. (Bulletin de la Société Royale Belge des Ingenieurs et des Industriels, 1950, Sept., pp. 181–192). An account is given of the developments in the manufacture of malleable or

nodular cast iron in America. It is pointed out that the magnesium addition method, producing as it does ductile cast iron with the characteristics of carbon steels, must be used with care and with regard to the uses to which the iron is to be put. A description is given of the properties of irons examined after various heat-treatments and with various alloying elements added.—J. J.

Gray Iron Preferred for Large Heavy Duty Crankshafts. A. Finlayson. (Materials and Methods, 1950, vol. 31, June, pp. 69–71). **Diesel Engine Crankshafts Cast In Gray Iron.** A. Finlayson. (Foundry, 1950, vol. 78, Aug., pp. 70–75, 150–154; Sept., pp. 92–97, 216, 217). The melting practice, using a 4-ton basic electric furnace, to produce several grades of high quality iron; pattern design and making, and moulding and core practice, for making cast crankshafts weighing from 500 to 5000 lb., from 6 to 18 ft. long, are outlined in detail. Information on the pouring conditions, the composition of a particular heat for a specific choice of casting, and the positioning of integrally cast test bars is also given, together with data on heat-treatment and inspection. From a study of the mechanical properties of cast crankshafts and cast test bars, the average tensile strength of the crankshafts was observed to be about 9% greater than that of the test bars. Photomicrographs are presented to show typical variations in microstructure along a 1000-lb. crankshaft.—E. J. D. S.

Chilled-Roll Manufacture. K. H. Wright. (Institute of British Foundrymen; Iron and Coal Trades Review, 1951, vol. 162, Jan. 26, pp. 185–192; Feb. 2, pp. 255–262: Foundry Trade Journal, 1951, vol. 90, Jan. 11, pp. 33–40; Jan. 18, pp. 61–68). After referring to the conventional straight carbon chilled roll, reference is made to the manufacture of rolls required for modern high-speed mills. These fall into two main types, the sharply defined and the indefinite chill. The influence of nickel in increasing the chill is offset by the reduction of the thickness of the sharply defined layer. The way in which this is overcome by additions of chromium is explained, a suitable composition for a 30-in. dia. roll being 3% C (total), 0·75% Si, 4·2% Ni, and 1·05% Cr. The effect of other alloying elements such as molybdenum and manganese is also explained. The duplex process has been developed to mitigate the practical difficulties of cracking and internal strains, to strengthen the core, to avoid persistent carbides, and to obtain the correct degree of austenitic transformation. The disadvantage of this system is the development of additional strains in the widely differing austenitic transformation temperatures of the shell and core. As the clearly defined chilled roll is confined to flat or shallow section work, the indefinite chill roll has been developed for profiles requiring deeper grooves, and where a high spall resistance, and fire-crazing resistance are required. The metallurgical structure required for such rolls is obtained by maintaining a correct carbon, silicon, and chromium balance. The use of the indefinite chill mould is expanding rapidly. The method of moulding and casting such a chilled roll is explained. Features are the machining of fine saw cuts in the chill-mould face to assist in removing gases, bottom pouring, and close temperature and analytical control of the molten metal. The metal is usually melted in an air furnace and the method of operation of a modern pulverized-fuel air furnace is described in some detail. Inspection involves visual surface examination and hardness determination by the Schore scleroscope.—J. E. W.

Steel Castings—Past, Present, and Future. J. F. B. Jackson. (Metallurgia, 1950, vol. 42, Nov., pp. 285–288). Progress in the production of steel castings during the last 21 years is reviewed under the following headings: Steelmaking for castings; mould refractories; gating and heading practice; mould and core production; cleaning operations; non-destructive testing; applications and specifications; and co-operative research within the industry.—J. B. B.

Technical Developments in Steel Casting in Great Britain. A. G. Thomson. (Australian Foundry Trade Journal, 1950, Nov., pp. 3–4). Under the aegis of the British Steel Founders' Association, attention has been concentrated on productivity, technical progress, and industrial health. The use of oxygen enrichment, the development of non-destructive methods of testing, the application of modern layout principles and modern mechanical handling plant have all contributed to increased productivity. As to working conditions, modern methods of dust control and a mobile X-ray unit have improved personal relationships in the industry.—J. E. W.

Navy Modernizes Foundry. E. Bremer. (Foundry, 1950, vol. 78, Sept., pp. 98–101). The modernizing and layout of a naval steel foundry, in which the size and number of castings produced do not favour a mechanized production system, are described.—E. J. D. S.

Determination of the Average Grain Size in a Foundry Sand. E. O. Lissell. (Gjuteriet, 1949, vol. 39, No. 11, pp. 165–172). [In Swedish]. A general account of different methods of determining grain size in sands, whether computed as average diameter or as fineness number, is presented, together with comparisons of results and desirable characteristics.—B. S. E.

A Method for Studying Mold-Metal Interface Reactions. R. E. Savage and H. F. Taylor. (Foundry, 1950, vol. 78, Sept., pp. 82–89). A test is described in which a steel pin is embedded in a standard sand test specimen and melted *in situ* by induction. The interface reaction and the products formed are observed to reproduce those occurring in sand moulds when molten steel is poured into them. Using X-ray diffraction, fayalite was the only metal–sand reaction product found in both foundry and laboratory test samples. The X-ray patterns of both samples were identical. The probable reactions between Fe (steel) and O (from the mould) → FeO, and $2FeO + SiO_2$ (sand) → $2FeO.SiO_2$, were dependent on time and temperature. The results of tests to show some of the effects of sand variations and the carbon content of the steel used are presented.—E. J. D. S.

Proposal for Storing Patterns and Storage Organization. K. G. Wiss. (Gjuteriet, 1949, vol. 39, No. 2, pp. 19–30). [In Swedish].

Rationalization of the Storage of Castings. K. G. Wiss. (Gjuteriet, 1949, vol. 39, No. 7, pp. 102–112). [In Swedish]. Fork-lift trucks in combination with stacking elements such as pallets and skids almost eliminate manual handling of materials, as shown by the transport and storage system introduced at the Skefco foundries. At the Katrineholm works about 12% of the total labour is employed in material handling, and up to 25% of the storage costs are estimated to be saved.—B. S. E.

Permanent Mold Casting of Gray Iron. H. Chase. (Foundry, 1950, vol. 78, Oct., pp. 110–113, 232–234). The mass production of light-weight iron castings is described. The metal moulds used are made from heat-resisting cast iron and generally have two or four cavities. They operate in automatic casting machines and after about 25,000 cycles are worn out and replaced. About 95% of the castings formed in these iron moulds require sand cores. Annealing of these small castings, weighing about 3 lb. and produced at a rate of about 45,000 per day, is necessary subsequent to knock out. This process is also automatic and continuous. The process as a whole is said to be less flexible than sand casting but well adapted to the class of work.—E. J. D. S.

Making Shell Molds of Resin and Sand. F. W. Less. (Foundry, 1950, vol. 78, Oct., pp. 162, 164, 168). A German method of making sand moulds known as the 'Croning' or 'C' process is described. [Details have already been given by B. N. Arnes, S. B. Donner, and N. A. Kahn; *see* Journ. I. and S. I., 1951, vol. 168, May, p. 97].

Moulding Technique. W. Pollock. (Institute of British Foundrymen: Foundry Trade Journal, 1950, vol. 89, Dec. 28, pp. 551–557). The techniques used by John Broadfoot and Sons, Glasgow, for the jobbing moulding of a large bulkhead door panel and frame, and a dome-shaped casting, are described. Details are also given of an adjustable moulding box, suitable for a jobbing foundry making 'one-off jobs' of medium size.—J. E. W.

Core Blowing. J. Buchanan. (Institute of Australian Foundrymen: Australasian Engineer, 1950, Dec. 7, pp. 86–89). The art of producing precision cores by accurately filling the core box with evenly rammed sand, by means of compressed air, is described in detail. Three different methods are outlined, and illustrated by 33 photographs. These methods are: (1) Blowing direct into, or on to, drying plates; (2) blowing into core boxes and turning out into drying plates; and (3) blowing cores in halves and closing together before baking.—P. M. C.

Core-Blower Application and Operation. G. W. Fearfield. (Institute of British Foundrymen: Foundry Trade Journal, 1951, vol. 90, Feb. 22, pp. 207–210; Mar. 1, pp. 229–233). The core-blowing machine is primarily a production tool, and is generally applicable for the production of small to medium

size cores. An adequate volume of air at a constant pressure, between 90 and 120 lb./sq. in. and free from excessive moisture must be provided. The sand should be free blowing, with a low moisture content, and of a medium or large grain size. Mixing is best done in a batch-type mixer. In making core boxes, the merits of cast iron over aluminium must be assessed with regard to its weight and its wear resistance. Co-operation between planning department, pattern shop, and core shop is essential to produce the best design. Recommendations are made regarding the position and size of blowing holes, the arrangement of loose pieces, and the provision of satisfactory parting lines. Various venting methods are discussed in detail, as well as defects arising from poor venting. Reinforcing agents should be made an integral part of the core. The design of the blowing head is discussed, and the importance of standardized core boxes and blowing-plate holes is emphasized.—J. E. W.

Investment Castings Depend on Good Pattern Tooling. R. L. Wood and D. von Ludwig. (Machinist, 1950, vol. 94, Aug. 26, pp. 1229–1240). The authors discuss the practical production of close-tolerance and often intricate castings by the lost wax process. They describe the manufacture and principles involved. The technique depends on the quality of the expendable patterns used. These patterns are usually wax, sometimes a plastic and infrequently frozen mercury, all of which must be produced in a mould or die. The design of the mould is critical in a process that requires the utmost attention to detail and technical ability at every stage. The mould must be easy to dismantle and the pattern withdrawn without damage or distortion to the latter. Care is required in location of cores, runners, and parting lines. Selection of low-melting point materials or machined steel mould components depends on circumstances. These are some of the aspects of pattern tooling that the authors discuss from considerable experience and illustrate through examples of good and bad practice. Accuracy of casting up to $\pm$ 0·002 in. is claimed for small castings made by the 'investment' casting process.—T. W. H.

Portable Air Tools in Foundry Practice. A. G. Ringer. (Canadian Metals, 1950, vol. 13, Sept., pp. 16, 19, and 36). The importance is stressed of proper selection and correct use of interchangeable pneumatic chipping hammers, core breakers, and grinders for foundry cleaning work. Examples of correct use of various types of tools are given. The importance of good maintenance is emphasized and use of worn tools is stated to cause serious loss of efficiency and drop in man-hour output.—E. C.

Foundry Mechanization by Means of Horse-Shoe-Shaped Roller Conveyors. I. Hurtig. (Gjuteriet, 1949, vol. 39, No. 9, pp. 135–140). [In Swedish]. The author summarizes the types of mechanization employed in Swedish foundries and compares their relative merits and importance in saving labour. The advantages of the 'horse-shoe' roller conveyor are pointed out and examples of British and Swedish layouts are given.—B. S. E.

Friction Saws Reduce Costs in the Foundry. H. J. Chamberland. (Gjuteriet, 1949, vol. 39, No. 10, pp. 152–154). [In Swedish]. Friction saws operating at high speed (35–75 m./sec.) are advantageously adopted for cutting alloys which are otherwise difficult to clean. The heat of friction partly melts the material. Normally the thickness should not exceed 25–35 mm. Figures are given for optimum speed and working capacities with different materials; the method is said to be specially suited for cutting stainless and manganese steels. B. S. E.

Dust Abatement by Sprays—A Wider Field of Application for Compressed Air. G. Widegren and G. Grönkvist. (Gjuteriet, 1949, vol. 39, No. 6, pp. 94–97). [In Swedish]. The dust hazards in foundries can be greatly allayed by means of moisture sprayed by compressed air; different equipment for this is described and detailed data given. The moisture makes the dust settle, and a relative air humidity of 50–70% facilitates its exhalation from the human air passages.—B. S. E.

Application of a Fluidity Test Mold. E. C. Hart. (Foundry, 1950, vol. 78, Oct., pp. 100–102). Improved control and efficiency of pouring practice for various steel melts was achieved by fluidity testing in the melting shop. The test mould, made by a core blower, differed from the accepted test mould by having the spiral radiating from the centre outwards. The total volume of mould metal was equal to that of the spoon sample, and a technique was devised to correct the fluidity test values for speed of casting, and finishing additions, etc., characteristic of various heats. A fluidity chart was developed to relate section thickness of casting to satisfactory fluidity of various steels, measured in inches of test spiral.—E. J. D. S.

HEATING FURNACES AND SOAKING PITS

Results with a Remodelled Roll-Over Furnace. E. Faber. (Stahl und Eisen, 1950, vol. 70, Nov. 23, pp. 1111–1115). The measures necessary to obtain maximum efficiency of a roll-over furnace are described. These include correct operation and furnace pressure conditions, waste gas valves, and complete combustion and central control. Although the cost of installing the necessary control equipment is high, it is soon repaid.—J. P.

The Operation of Soaking Pits: Importance of Ingot Heat Conservation. J. Dodd. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 29, pp. 1029–1032). The author stresses the need for further research into ingot heat conservation, and in this connection discusses the more efficient use of soaking pits. Close liaison between melting shop, soaking pits, and rolling mills is essential, and the system of soaking pit planning adopted at the Appleby-Frodingham Steel Co. is described. He also discusses the proper maintenance of soaking pits in order to ensure maximum availability, and finally suggests a modified soaking procedure to conserve ingot heat.—G. F.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Progress in Heat Treatment in the Last Twenty-one Years. P. F. Hancock. (Metallurgia, 1950, vol. 42, Nov., pp. 329–333). Progress in heat-treatment in the last 21 years is reviewed under the following headings: Temperature control and distribution; atmosphere control; mechanization; new heating methods; and developments in processes.—J. B. B.

Heat Treatment or Hot Working? A. Leon. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1950, vol. 5, Oct. 31, pp. 428–431). This article clarifies German nomenclature so as to distinguish true heat-treatment processes, in which structural changes are brought about solely by the action of temperature and time, from hot working processes, which are defined as processes in which the material is permanently deformed by mechanical working at a temperature above the recrystallization limit.—H. R. M.

Thermal Treatments Accompanying Cementation. J. Pomey. (Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 789–804; Dec., pp. 895–906). The aim of cementation is to give a hard layer in a state of compression. The metallurgical conditions of fabrication of cemented pieces and the control of cementation and quenching conditions are discussed, and the methods of avoiding deformation during thermal treatment given. A classification of hardening and cementation treatments is made, the newest process being carbo-nitriding at a temperature between the iron–carbon and iron–nitrogen eutectoid temperatures giving a resilient pearlite core and fine austenitic surface. The principle of adaptation and the useful rôle of retained austenite are discussed and the fields of application of different cementation processes noted, together with industrial applications.—A. G.

Overhead Radiant Heat Aids Axle Forging. H. Chase. (Machinist, 1950, vol. 94, Aug. 12, pp. 1173–1176). The article describes the heat-treatment of axle shafts at the new Canton Forge Division of the Ford Motor Co. Production starts with the shearing to length of bar stock S.A.E. 8630 or 1330 steel. Shafts are forged, heat-treated, straightened, and carried out on a conveyor line system. There are 16 vertical Selas radiant heating furnaces. The cycle of treatment is heat to 2000° F. and then forge in six passes through Ajax rolls and swage under a 1500-lb. Erie steam hammer. The forgings are reheated to 2250° F. at a second Selas vertical furnace and flanged in five operations in a 6-in. National upset forging machine. A chain conveyor takes the forgings to a Holcroft continuous hardening furnace, the forgings are heated to 1500° F. and then quenched vertically in a 10% caustic soda solution, except for the flange which is kept soft for machining purposes. Forgings are then shot-blasted with steel shot, straightened, and inspected. This installation can deal with 600 shafts per hour.—T. W. H.

Heat Treatment of Steel Castings. H. Gau and W. Küntscher. (Die Technik, 1950, vol. 5, Oct., pp. 519–521). This is a brief

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account of experiments carried out in the Henningsdorf steel foundries and rolling mills with the object of improving the heat-treatment of steel castings. These experiments have led to a redesign of the heat-treatment shop. The chief features of the recommended treatment are : Annealing temperatures in the region of 950–1100° C., followed by air quench to about 600° C. and cooling in sand ; corrective treatment for faulty charges in the form of normalizing, followed by 1–2 hr. alternately at 650–670° C. and 720–750° C., the number of cycles being determined by trial.—J. G. W.

The Increase in the Ductility of Tempered High-Speed Steel. W. Kowalski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 357–358). [In Polish]. High-speed steel tempered at 880–900° C. behaves well on cutting, but presents difficulties on cold working. To increase the ductility of softened steel additional heat-treatment for 2 hr. at 720–740° C. with subsequent fast cooling is proposed. Experiments showed that the processes causing brittleness of this steel take place between 550 and 600° C. It is therefore important to pass this temperature range quickly when cooling.—V. G.

Modern Heat Treatments of Tool Steels and Particularly of High-Speed Steels. M. de Courcel. (Métaux et Industries, 1950, No. 2, pp. 33–38, 49). The author discusses the rates of change of austenite into martensite and into bainite, for various temperatures of reheating, and of the quenching medium, with particular reference to a molybdenum steel. N. MCE.

Steels for Case-Hardening and Nitriding. F. Brühl. (Stahl und Eisen, 1950, vol. 70, Nov. 9, pp. 1060–1063). The composition and properties of the standardized steels for case-hardening and nitriding are reviewed. The steels and processes used for nitriding in Germany are the same as those employed in other countries.—J. P.

Modern Methods of Heat-Treating Tool Steels, especially High-Speed Steels. A. Michel. (Mémoires de la Société Royale Belge des Ingenieurs et des Industriels, 1949, Series B, Sept., pp. 155–170). A description is given of work performed on the effects on the mechanical properties of tool steels, especially high-speed steels, of various forms of heat-treatment. The mechanical properties are correlated with the metallurgical structures of the steels, and the extent of the austenite transformation taking place in the course of the heat-treatments the steels have received. **S**-curves and other transformation curves, obtained dilatometrically, are given for various types of steels under various conditions.—J. J.

Modern Engineering Materials. F. R. Morral. (Tecnica Metalurgica, 1950, vol. 6, Apr., pp. 105–120). [In Spanish]. The author surveys technical progress in the field of engineering materials in the last 25 years. He mentions the principles of the use of oxygen, treatment of low-grade ores, transformation of austenite, hardenability numbers, weldability, precipitation hardening, continuous casting, and use of isotopes, and indicates how each development fits into the picture as a whole. The heat-treatment processes are divided into two groups : Those aiming at a final minimum hardness, and the simple hardening processes. He examines earlier ideas on heat-treatment phenomena.—R. S.

Carbon Restoration Improves Wear Resistance. S. Damon. (Steel, 1950, vol. 127, Oct. 23, pp. 66–67). The process of restoring the carbon lost from the surface of steel parts during hot working is being used to improve wear resistance and fatigue strength. A method of controlled atmosphere for recarburization, using regulation of the dewpoint to alter the carbon pressure, is described.—A. M. F.

Processing the Clad Steels. R. Mansell. (Steel Processing, 1950, vol. 36, Dec., pp. 605–611, 645). Low-carbon steel, clad with various grades of stainless steel, nickel, Monel, Inconel, or cupro-nickel, is finding increased importance and applications, particularly in the heavy process chemical industries. Besides the usual saving in cost, the clad sheet is more easily worked (by virtue of its low carbon steel core) than a solid sheet of the cladding metal would be. The author describes in a general manner various techniques employed in fabricating, heat-treating, and finishing these materials, with special reference to stainless clad sheet.—P. M. C.

Liquid Carburizing. D. A. Colwell. (Australian Institute of Metals : Australasian Engineer, 1950, Dec. 7, pp. 60–62). The reactions involved in liquid carburizing result apparently in the formation of nitrogen and carbon from reactions involving the production of cyanate and/or cyanamide radicles. Accelerated baths aim at preventing the formation of free nitrogen by these reactions without inhibiting the production of atomic carbon.—P. M. C.

Thermodynamics of Surface Impregnation Processes. G. M. Willis. (Australian Institute of Metals : Australasian Engineer, 1950, Dec. 7, pp. 50–52). The chemical potentials of elements can be used as a quantitative measure of their tendency to enter a metal from another phase. The chemical potentials of carbon in steels and in some gas mixtures as a function of carbon content are calculated, and used to illustrate the relations involved in carburizing. The chemical potentials of nitrogen in the metal and gas phases occurring in nitriding are shown, and the effect of alloying elements which form stable nitrides is discussed briefly.—P. M. C.

The Kinetics of Decomposition of Gases at Metal Surfaces. M. F. R. Mulcahy. (Australian Institute of Metals : Australasian Engineer, 1950, Dec. 7, pp. 53–56). The theory of the kinetics of decomposition reactions at metal surfaces is reviewed. The results of published experiments on the rate of deposition of carbon from methane and of nitrogen from ammonia are briefly described. Some general observations are made on the relative rates of decomposition of the gas at the surface and subsequent diffusion of the product in the carburizing and nitriding processes.—P. M. C.

Surface Hardening by High-Frequency Induction Heating. F. Strasser. (Tecnica e Industria, 1950, vol. 28, May, pp. 493–497). [In Spanish]. The principles and equipment for induction heating are described. The advantages of high-frequency surface hardening are : Rapidity ; clean equipment can be mounted near machine tools ; distortion is largely avoided ; scaling is reduced ; original core ductility is maintained ; precise control of the exact area of hardening guarantees uniformity of product ; reduced costs (no subsequent heat-treatments are required, there is less handling, the risk of human error is almost eliminated). Its main limitation is that it can be used only for mass production of parts.—R. S.

Selective Hardening Enables Machine Speed Up. D. Godby. (Iron Age, 1950, vol. 166, Nov. 2, pp. 93–94). The Dynaflow transmission plant of General Motors is using induction hardening only where needed on transmission parts, thus enabling higher machining speeds to be used.—A. M. F.

Some Experiences with Induction Heat Treatment. F. P. Heard. (Australian Institute of Metals : Australasian Engineer, 1950, Dec. 7, pp. 81–85). A brief preliminary description is given of the skin heating effect of high-frequency currents. The effect of frequency on the depth of penetration, in iron in the ferro- and para-magnetic states, is tabulated. Many applications of this method of heating for heat-treatment are described and illustrated, with particular reference to the production of automobile parts.—P. M. C.

S-Curves as an Aid in the Heat-Treatment of Steels. O. Nordin. (Värmländska Bergsmannaföreningens Annaler, 1950, vol. 1, pp. 99–126). [In Swedish]. The elements of microscopical and dilatometric methods of obtaining **S**-curves are touched upon, and some diagrams for general tool steels are discussed in the light of their significance for different heat-treatments.—B. S. E.

Master Curves Simplify Stainless Tempering. A. E. Nehrenberg. (Steel, 1950, vol. 127, Oct. 23, pp. 72–76, 88). The author describes the use of master tempering curves for planning commercial tempering treatments for hardenable stainless steels, and presents a new chart for eliminating the complex mathematical calculations formerly required. This chart gives the relationship between temperature and time for various values of the tempering parameter which is defined as $T(C + \log t)$ where T is the absolute temperature, t is the time, and C is a constant taken as 20. The chart can also be used for evaluating the effects of elevated service temperatures on the hardness of quenched and tempered steels.—A. M. F.

FORGING, STAMPING, DRAWING, AND PRESSING

The Use of Hot Compressed Air in Forges. K. Pilinski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 345–350). [In Polish]. The use in forges of hot compressed air is discussed and air preheaters are briefly described.—V. G.

'Flakes' in Steel Parts. A. Portevin and E. Pretet. (Comptes Rendus, 1950, vol. 231, Nov. 27, pp. 1188–1190). Flakes are internal fissures without thickness, revealed but not caused by rupture, whose appearance and orientation are independent of the conditions of rupture. In ingots they

occur only inside the superficial layer of basaltic crystals. After forging, flakes are found in surfaces parallel to the direction of working and are a maximum for a certain reduction in section, generally small. During a rolling sequence orientation is always normal to the last effort applied. Flake formation can be minimized by : (*a*) Reducing segregation by soaking at high temperatures ; (*b*) forging ingot to its final shape in two or more heats with intermediate cooling ; (*c*) control of the rate of cooling after forging, flakes being only produced at medium speeds ; and (*d*) avoiding too great a temperature difference between the surface and core of the steel during forging.—A. G.

Roll-Edging Forging Blanks Saves Steel. (Steel, 1950, vol. 127, Oct. 30, p. 61). The Ford Motor Co.'s forge division are preforming the edges of forging blanks in gap rolls before the forging operation. This is said to increase production and no edger impression in the forging dies is required, thus involving less costly dies.—A. M. F.

The Technique of Drop Forging. K. L. Buckle. (Journal of the Junior Institution of Engineers, 1951, vol. 61, Part 8, pp. 269–291). The paper is a general survey of drop forging design and production.—R. A. R.

Die-Block Steels for Drop Forging. H. J. Merchant. (Metal Treatment and Drop Forging, 1951, vol. 18, Jan., pp. 13–21, 24). The author enumerates the requirements and selection of steels for die blocks, reviewing the types of steel employed. The methods of fabrication, heat-treatment, hardness, and testing of die-block steels are discussed. Brief reference is made to future trends. Four tables show typical steel analyses, hardnesses, applications, and tolerances.—P. M. C.

New Methods of Fabricating Fittings by Stamping, Welding and Machining. K. Krekeler. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Oct. 21, pp. 833–836). Fabrication of valves and fittings from stamped parts offers obvious advantages. The interior is accessible during manufacture and may be given a better finish, and the finished product is stronger. In this connection it is possible to improve the method of manufacture by the use of jigs which enable all welding seams to be completed in one setting. Photographs and drawings illustrate the method. In this connection flash butt welding is of particular value.—J. G. W.

Stage by Stage in Tooling a Tricky Pressing. J. A. Grainger. (Machinist, 1950, vol. 94, July 22, pp. 1067–1073). The author describes the initial and final designs for press tools used in the production of a light steel casing for a car heater unit, produced as a deep-drawn pressing from first quality mild steel. Difficulty was experienced in drawing due to the awkward shape, notably the re-entrant angle blending into the angular and curved ends of the casing.—T. W. H.

How to Select a Mechanical Press. S. D. Brootzkoos. (Machinist, 1950, vol. 94, July 22, Suppl., pp. 1–6). The author shows how the correct selection of a mechanical press presumes a knowledge of press construction, production methods for stampings, die design, and strength of materials. He explains how pressures can be calculated for presswork operations divided into four major groups, namely, shearing, drawing, bending, and squeezing. He gives accepted rules and formulæ for estimating a suitable press size, and includes an original chart which gives the relationship between midstroke capacity and bottom stroke, or rated capacity for presses in common use. A table gives the strength of materials in plate and strip form for ferrous and non-ferrous metals, also for cardboard, fibre, leather, and paper.—T. W. H.

The Bolt Industry in Central France. (Aciérs Fins et Spéciaux Français, 1950, Nov., pp. 21–22). The production of bolts, rivets, nuts, etc., from mild or semi-mild steels is described. The steels used in the tools for both cold and hot working of these products are given. These include 0·8% carbon steels, chromium–nickel–molybdenum steels, nickel–molybdenum steels, and high-speed steels.—E. C. S.

Reduction of Internal Stress in Cold-Drawn Bars. H. Bühler and E. H. Schulz. (Stahl und Eisen, 1950, vol. 70, Dec. 7, pp. 1147–1151). The internal stress in heavily reduced steel bars can be reduced by 70–90% by giving a subsequent light pass. The surface properties and tensile strength of the bars are not adversely affected. The process is readily applied to bars of 20 mm. and upwards in diameter and is superior to existing methods of stress reduction.—J. P.

Manufacture of Deep Drawing Steel. R. W. Evans. (Swansea Metallurgical Society : Engineer, 1951, vol. 191, Mar. 9, pp. 306–309 ; Mar. 16, pp. 338–340). This article gives a comprehensive review of the manufacture of deep-drawing steels together with considerable technical and metallurgical data on the latest techniques. The problem is clearly defined and deep drawing operations described. The properties required for deep-drawing steels are considered in detail in respect of the steel ingot, the steel composition, and the effects of age hardening. The raw materials, the effect of sulphur in the fuel, the pig iron, scrap, limestone, lime, and fluorspar are all considered. The exacting conditions both furnace structure and hearths undergo in the manufacture of these sheets are dealt with. Furnace maintenance, design, and repair are discussed together with plant layout. English and American practices are compared.—M. D. J. B.

A New Method of Storing Rod. A. F. Anjeskey. (Wire and Wire Products, 1950, vol. 25, Dec., pp. 1052–1055, 1091). The author describes a new method for storing rods and wire, which contributes to efficiency in the handling of materials. It consists of vertical stacking between steel-pipe guides 22 ft. high. An overhead crane with hydraulically operated expanding lifting fork is used for handling. Experience shows that the vertical stacking method makes more efficient use of space, facilitates the separation of different qualities of rod, and the overall cost is less.—J. G. W.

Cold Extrusion of 105 mm. Shells Saves Steel. D. L. Brown. (Iron Age, 1950, vol. 166, Oct. 19, pp. 69–75). Cold extrusion of shells at Mullins Manufacturing Corp. has reduced steel requirements by 40%. This reduction is obtained because the product requires little or no machining and has a smooth finish. The manganese content of the steel may also be reduced and heat-treatment eliminated, the mechanical properties required being achieved by cold working. The extrusion sequences used and the hardness distributions and grain flow obtained are described ; it is shown how defects in the metal are smoothed out.—A. M. F.

Progress in the Cold Working of Metals 1929–1950. W. C. F. Hessenberg. (Metallurgia, 1950, vol. 42, Nov., pp. 334–336). Progress in the cold working of metals during the last 21 years is reviewed under the following headings : Cold rolling ; wire drawing ; deep drawing and pressing ; and impact extrusion.

Wire-Drawing Research. J. G. Wistreich. (Metal Treatment and Drop Forging, 1951, vol. 18, Jan., pp. 22, 24). This is a short review of recent work on alloy steels carried out by Lueg and Pomp. A silver steel, a high speed Cr–W–V type steel, and an 18/8 stainless were used in experiments concerned with the efficacy of salt as a lubricant coating, and with the effect of drawing speed on drawing force. The dependence of drawing force on die angle, reduction, and friction was also investigated, and it was concluded that all the present theories for the drawing process are inadequate.—P. M. C.

Empirical Graphical Method for the Determination of Drawing Force. M. Schneider and R. Wusatowski. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 11–16). [In Polish]. Using Lueg and Pomp's results the authors constructed diagrams of field of scatter for the following relations : $P = f(\%\ r.p)$; $\eta_0 = f(\%\ r.p)$; $a_{0\cdot2} = f(\%\ r.p)$ and $\sigma_1/H_B = f(\%\ r.p)$, where : P = drawing force, η_0 = coefficient of deformation efficiency, H_B = Brinell hardness, $a_{0.2}$ = yield strength, and $r.p$ = area reduction. For calculation of drawing force the relation $\sigma_1/H_B = f(\%\ r.p)$ is the most satisfactory as the scatter is the smallest compared with the others. The results of the authors' measurements of drawing force and hardness for low carbon steel rods calculated in terms of σ_1/H_B are within values given by Lueg and Pomp. The authors plotted a mean curve for the relation $\sigma_1/H_B = f(\%\ r.p)$ from which they obtained a general empirical formula for calculating the drawing force for various kinds of steel rods and wires. With this a nomogram was constructed which permits rapid calculation of the drawing force.—V. G.

Process for Measuring Drawing Dies. C. Eisenhuth. (Stahl und Eisen, 1950, vol. 70, Dec. 7, pp. 1153–1154). A method is described for measuring the bearing length of dies using a probe of known taper. The method is simple, rapid, and readily used by unskilled operatives.—J. P.

Temperature Measurement in Rod and Wire Drawing and the Problem of Supercritical Drawing Speeds. W. Reichel. (Stahl und Eisen, 1950, vol. 70, Dec. 7, pp. 1141–1145). The temperature developed at the contact between metal and working tool can be used as a criterion for the suitability of tool design, drawing speed, and lubricant in wire drawing. Temperature can be measured by a new method in which the die and the wire or two halves of a split die serve as the

XUM

two members of a thermocouple. Application of the technique to single and multiple draws is described. A comparison of the changes of temperature with increasing speed in machining and plastic deformation suggests that there should be a critical drawing speed beyond which die temperature should decrease. It is proposed to carry out investigations into this matter, in view of its importance in future draw-bench design.—J. P.

ROLLING-MILL PRACTICE

New Relationships in the Calculation of Spread during Rolling. E. Cotel. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1219–1222). Two approximation formulæ are proposed for the calculation of spread during rolling with reductions greater than 45%. Spread calculated therefrom is in good agreement with observed values.—J. P.

Spread during Hot Rolling of Steel. H. Bechmann. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1222–1223). A formula has been derived relating initial slab thickness and width, radius of rolls, and reduction in thickness with spread during hot rolling.—J. P.

Electric Drives for Reversing Hot Mills. P. E. Peck. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 309–323). Consideration is given to the power demands made by the rolling process and to the response which must be expected from the drive. The electrical and mechanical characteristics of the main-drive motor are described before dealing with the drive itself. Single- and twin-motor drives are compared from various aspects. The advantages of the twin-motor drive are stated. The factors governing the design of the main-motor generator set are explained and systems for lubrication and ventilation are described. The requirements and capabilities of the control scheme are summarized and a description is given of one form of modern control scheme using rotating regulators. The paper concludes with a reference to the performance which can be expected from the modern mill.

Rectifiers for the Supply of Power to Rolling Mills. L. Tarnowski. (Hutnik, 1951, vol. 18, Feb., pp. 54–61). [In Polish].

New Bearing Materials. L. Andrejew and Z. Sobczyk. (Hutnik, 1950, vol. 17, Nov.–Dec., pp. 424–427). [In Polish]. Bearing materials for rolls made from woods 'Lignoston' and 'Lignofol' developed in the U.S.S.R., methods of their manufacture, and the constructions of the bearings are described. Properties of these materials are compared with bronze and synthetic-resin-impregnated fabrics.—V. G.

Operating the World's Fastest Mill—Control. G. A. Kaufman. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 76–82). Methods of controlling the operation of the 42-in. five-stand tandem tinplate mill of the Jones and Laughlin Steel Corp. are described and characteristic charts showing acceleration, deceleration, jogging, motor line current, speeds, generator voltage, and tension reel current are given. Information on the auxiliary equipment of the mill is also included.

M. D. J. B.

Operating the World's Fastest Mill—Operations. J. R. Powell. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 73–76). This paper describes the operation of the 42-in., five-stand, tandem mill at the Aliquippa works of Jones and Loughlin Steel Corp. which started in October 1947. The mill is to produce tinplate and its allied products. Rolling speeds, gear ratios, stands, housings, lubrication, cooling, pickling plant, and X-ray finish gauge equipment are described.

M. D. J. B.

New Rolling-Mill Plant at the Normanby Park Steelworks of John Lysaght's Scunthorpe Works, Ltd. A. H. Norris. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 15, pp. 915–922). *See* Journ. I. and S.I., 1951, vol. 167, Mar., p. 346.

The Possibilities of Economic Utilization of Rolled Products. Z. Wusatowski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 310–321). [In Polish]. The possibilities of more economy in rolling by suitable utilization of size and weight tolerance limits are considered. The limitation and standardization of profiles and sizes of rolled products, the problem of rationalization of their shape, and the use of steels of higher strength are discussed.—V. G.

Tyre Rolling Mill: Installation of Grid Controlled Rectifier Equipment. (British Steelmaker, 1951, vol. 17, Feb., pp. 79–81). **Equipment for Steel Tyre-Rolling Mill: Mercury-Arc Rectifier for 800-h.p. Motor.** (Iron and Coal Trades Review, 1951, vol. 162, Feb. 2, pp. 268–269). **Rectifier for Tyre-Rolling Mill.** (British Engineering, 1951, vol. 33, Mar., pp. 1000–1002). A description is given of new equipment installed at the Kilnhurst Works of John Baker and Bessemer, Ltd., which provides a variable voltage D.C. supply for an existing 800-h.p., 500-V., 750-r.p.m. motor driving the inner roll of a tyre-rolling mill. The D.C. motor drive, which replaces a reciprocating steam-engine drive, derives its power from a 400-kW. G.E.C. pumpless, air-cooled, steel tank, mercury-arc rectifier. The design and operation of the new equipment are described.—G. F.

19-Stand Rod Mill of Keystone Steel and Wire Co. W. Herman. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 91–95). This 19-stand rod mill with two loops has only two bars in the first nine stands and as many as four bars in the last ten stands simultaneously, with an average of three bars continuously. The mill normally operates a 480-lb. billet which gives a three-bar average. A layout drawing and detailed technical information are given with data on mill speeds, diameters, and areas. Production capacity is 950 tons/day. Details are also given of the method by which the proper co-ordination between the feeder, shear man, and reel man is obtained.—M. D. J. B.

Standard Belgian Mill Adapted for South American Use. E. C. Peterson. (Steel, 1950, vol. 127, Nov. 6, pp. 96–101). Details of the layout and construction of a mill developed by the Birdsboro Steel Foundry and Machine Co. for the Acero del Pacifico steel plant in Chile are given. The mill is of the Belgian type, designed to produce rounds $\frac{3}{8}$–2 in., angles $\frac{3}{4} \times \frac{3}{4} \times \frac{1}{8}$ to $3 \times 3 \times \frac{1}{4}$ in., flats 4×9 in., strip and skelp up to 10 in. wide and 0·102 in. thick, and rods from No. 5 up to $\frac{6}{16}$ in. in dia. All stands are two-high and there is an 18-in. rougher, three 14-in. and two 12-in. stands; in addition, there are two 10-in. stands for $\frac{3}{8}$-in. rounds, strip, skelp, and rods, and a group of six stands for finishing rods.—A. M. F.

Factors Influencing the Variations of Thickness in Rolling Sheets and Strips. Z. Wusatowski. (Hutnik, 1950, vol. 17, pp. 415–423). [In Polish]. The shape of the cross-sections of rolled sheets and strips, stresses in them, pressure of metal on rolls during rolling, influence of heat on rolls, methods of cooling, and polishing of rolls for hot and cold working are described. The factors influencing variations of thickness in rolling sheets and strips are discussed.—V. G.

Recent Progress in the Production and Fabrication of Stainless Steels. (Metallurgia, 1950, vol. 42, Dec., pp. 367–371). The new plant of Firth-Vickers Stainless Steels, Ltd., at Sheffield, is described. It will produce stainless-steel strip from 10 to 30 gauge in thickness, and up to 1 m. wide, in all the popular qualities. Some recent fabricating techniques for use with austenitic stainless steels are reviewed. Brief reference is made to some recently developed heat-resisting alloys.—J. B. B.

The Cooling of Special Steels during Rolling. M. Cabane. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1950, vol. 47, Dec., pp. 930–936). Trials have been carried out under controlled conditions in six works on a manganese–silicon steel, a cast steel, nickel–chromium, auto-quenching, 18/8, and 13% chromium steels. The variation of final depth and width of the rolled steel with rolling temperature is described and an index of widening derived. The effect of mode of heating, diameter of roll, and train speed on widening is noted.—A. G.

MACHINERY FOR IRON AND STEEL PLANT

Notes on the Rationalization of Steam Heat Generating Plants. L. Chiappa. (Calore, 1950, vol. 21, Nov., pp. 429–431). [In Italian]. A review of existing methods in heat generating plants is given and a number of suggestions are put forward to improve utilization. The use of old boilers as heat accumulators and various types of evaporator for concentrating aqueous solutions are considered.—M. D. J. B.

A Method of Checking Design Constants in Partial Recovery Steam Turbines. V. Grazioli. (Calore, 1950, vol. 21, Nov., pp. 426–428). [In Italian]. A simple method of checking the design consumption figures in calories of steam and fuel is described. The method is illustrated by a practical example and considerable operating data are given.—M. D. J. B.

Electric Arc Furnaces—Problems and Solutions in Power Supply. B. M. Jones. (Edison Electric Institute Bulletin,

1951, Feb., pp. 39–46). Difficulties encountered by an electricity supply company in connection with supplying electric arc furnaces ranging from 1500 to 15,000 kVA. are discussed, and diagrams of the line connections and the measures adopted, particularly to deal with voltage flicker, are presented.—R. A. R.

Hydraulic Baling Press for Light Scrap. Kühn. (Demag News, 1951, Jan., p. 21). A hydraulic press for baling light scrap such as strip, punchings, and wire is described. It operates on hydraulic power as available from any water system under a pressure not less than 4 atm. gauge. Its capacity varies between 10–15 bales/hr. of 20 kg. each. Its special advantage is its small size.—D. H.

A Scrap Metal Baling Press. (Engineer, 1951, vol. 191, Feb. 2, p. 159). A description is given of a self-contained, single-compression press for producing bales from 1 cwt. to 2 cwt. in weight and which are 16 in. × 24 in. and 6 to 8 in. thick, depending upon the loading of the press box. The press is manufactured by Fielding and Platt, Ltd., Gloucester. The working time cycle of the press is 75 sec. and it is designed to make 48 cycles/hr. The press is hydraulic, powered by a Fielding high-speed variable delivery radial pump driven by a 12·5 h.p. continuously rated squirrel-cage motor.

M. D. J. B.

Design of Crane Control. J. D. Leitch. (Symposium on Crane Control : Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 70–77). This paper is concerned only with electric overhead travelling cranes operated by D.C. motors and controlled by magnetic means. Motor ratings are discussed in detail and considerable information is given on the selection of resistors, brakes, contactors, overload relays, crane protective panels, acceleration relays, limit switches, and types of controller.—M. D. J. B.

Crane Resistor Design. M. A. DuBois. (Symposium on Crane Control : Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 77–78). The author discusses briefly some of the principal points to consider when designing resistors for crane drives.

M. D. J. B.

Electric Control of Twin Bridge Drives with No Torque Shafts. H. Ball. (Symposium on Crane Control : Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 78–81). This paper is written for the purpose of introducing the idea of eliminating line shafts on crane bridge drives by one of two means ; either through proper construction of bridge girders and end ties, or by synchronization of the motors located at opposite ends of the bridge.—M. D. J. B.

Possibilities of Standardizing Crane Control. J. A. Cortelli. (Symposium on Crane Control : Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 81–86). The author deals with the much needed standardization of parts and types and the problems which must be overcome before this can be achieved.

M. D. J. B.

230 h.p. Diesel-Electric Locomotive for a Steel Works. (Engineer, 1951, vol. 191, Feb. 16, pp. 220–221). A description is given of the two Diesel-electric locomotives recently designed and built by the Yorkshire Engine Company, Ltd., Sheffield, for Steel, Peech, and Tozer, Ltd. They have been specially designed for the severe working conditions prevailing in steelworks. They are capable of developing a starting tractive effort of 24,000 lb. and are powered by Davey Paxman six-cylinder oil engines developing 230 b.h.p. at 1250 r.p.m. driving British Thomson-Houston three-winding, self-ventilating D.C. generators.—M. D. J. B.

Diesel-Mechanical Locomotive for Steel Works. (Engineering, 1951, vol. 171, Jan. 19, p. 70). This article describes a Diesel-mechanical locomotive built by Andrew Barclay Sons and Co., Ltd., Kilmarnock, for the Workington Iron and Steel Company. The locomotive has been specially designed and constructed to withstand the arduous conditions in steelworks. It has a short 0–4–0 wheel arrangement enabling it to negotiate sharp curves. The Diesel engine is a six-cylinder Paxman RPH type, developing 300 b.h.p. at 1350 r.p.m.—M. D. J. B.

Hot Strip Mill Flying Shear at John Summers and Sons Ltd., Shotton. A. Asbury. (English Electric Journal, 1951, vol. 12, Mar., pp. 30–33). Since the flying shear was finally commissioned in March 1950, the electronic equipment has been in continuous operation. It is possible to cut lengths of plate which are consistently within $\frac{1}{2}$ in. and, under most favourable conditions, $\frac{1}{4}$ in. of the desired length. This applies over the whole range of operating conditions, *i.e.*, 800–1400 ft./min. strip speed and 12–22 ft. cut length.—B. G. B.

The Application of Electricity to Industry with Special Reference to Iron and Steel Works. R. Mathieson. (Journal of the Junior Institution of Engineers, 1951, vol. 61, Feb., pp. 157–177). The paper assembles and collates facts to provide the mechanical engineer with a useful reference and to give him a better understanding of the equipment that drives the plant he designs. Electric motors are discussed in fair detail and the advantages and disadvantages of each type are briefly given—all with particular reference to steelworks operations. Motor control gear is considered and the use of rectifiers mentioned. The Selsyn and its uses, and electrical heating and lighting are briefly discussed.—D. H.

Supervisory Control and Telemetering as Cost Reduction Tools. E. W. Head. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 83–87). A description is given of the scope and application of supervisory control and telemetering. The possible uses these methods might have in the iron and steel industry are discussed. Supervisory control to check circuit breakers in electrical distribution systems will reduce operating expenses and improve efficiency. Similarly the use of telemetering load-consumption information from various points will allow more efficient use of plant-generated power. Modes of operation and technical details are reviewed and stress is laid on the economy which can be achieved by these methods.—M. D. J. B.

Fire Protection for Electrical Equipment. J. T. W. Babcock. (Iron and Steel Engineer, 1951, vol. 28, Jan., pp. 96–100). A review is made of some of the fire protection and extinguishing requirements suggested by the insurance carriers for the control and reduction of fire waste. The best location for transformers, the practice of extending automatic sprinklers over transformer banks, the proper venting of transformers filled with non-inflammable dielectrics, and the use of dry transformers are discussed in detail. The risks of fire in switches, insulator brushings, and circuit breakers are also examined. The author suggests that the use of water should be accepted as inevitable and not completely disastrous, and quotes instances where thoroughly soaked motors have been completely dried out and renovated. The alternative to water sprinklers may be completely burnt-out motors.

M. D. J. B.

WELDING AND FLAME-CUTTING

The Physical Metallurgy of Gas–Metal Reactions in Fusion Welding. M. Hatherly. (Welding Engineering Symposium : Australasian Engineer, 1950, Nov. 7, pp. 81–88). The principles of gas–metal relationships and their bearing on the absorption of gases during fusion welding are briefly outlined. The effects of absorbed gases during solidification of the weld metal are discussed with particular reference to the development of gas porosity in steel, copper, and aluminium. Reference is also made to the effect of absorbed gases on the parent metal adjacent to the weld. There are 15 references.—P. M. C.

For Inert Gas Shielded Welding—Argon or Helium? J. Berryman. (Iron Age, 1950, vol. 166, Oct. 12, pp. 155–157). The author discusses the differences in performance between argon and helium in inert gas shielded welding. The latter gas providing a hot arc, deeper and more effective penetration, and faster travel speeds, but the arc is harsher and inclined to spatter. The argon arc by comparison is quite smooth and soft with shallow penetration. However, with an inert gas shielded metal arc (consumable electrode) a mixture of the two gases may be used in any proportion to give the desired characteristics.—A. M. F.

Chemical Composition of Austenitic Electrodes and Crack Susceptibility of Weld Deposits. R. Montandon. (Brown Boveri Review, 1950, vol. 37, July, pp. 255–264). Tests on 40 different commercial electrodes showed that more than half of the deposits exhibited cracks when tested by a modified Swinden-Reeve method. Investigations in the Brown Boveri laboratories demonstrate that : (1) Crack susceptibility diminishes with increasing ferrite content ; (2) crack susceptibility is greater with stabilized alloys and must therefore be attributed exclusively to the niobium content ; (3) electrodes with lime coatings are less inclined to cause cracking of weld deposits than neutral or titania-coated electrodes ; and (4) when welding ferritic material root passes should be made with heavy-gauge electrodes and a relatively low current. Advantages of using ferritic rather than austenitic electrodes to weld ferritic base materials are : (*a*) In structure and

composition the materials correspond more closely ; (*b*) ferritic materials contract approximately 50% less ; (*c*) higher tensile strengths are obtained ; and (*d*) they are considerably cheaper.
R. A. R.

Welding Electrodes and Rods. H. R. Clauser. (Materials and Methods, 1950, vol. 32, Dec., pp. 67–82). One of the most important requirements for producing a satisfactory welded joint, is the use of the proper filler metal. The selection of this filler is often quite difficult because of the many variables involved, and because of the great variety of electrodes and welding rods from which to choose. This article is a guide which covers all the standard-type electrodes and rods for joining the common ferrous and non-ferrous metals and alloys, including irons and steels, copper-base alloys, aluminium, magnesium, nickel alloys, zinc, and lead. Twelve tables give compositions, properties, and applications of all the standard electrodes and rods.—P. M. C.

On the Weldability of High-Tensile Structural Steels. A. Nacher. (Metallurgia Italiana, 1950, vol. 42, Dec., pp. 456–472). The very rapid heating during welding leaves the carbon undissolved and ready to form foci for crystallization during the cooling. The author suggests that reliable information on weldability can be obtained by taking Vickers hardness numbers and examining the structural alterations in the neighbourhood of a single run of weld metal deposited under normal conditions. The test can be made more severe by depositing the weld under water. Tests carried out on a number of alloy steels show that the maximum hardness caused by welding depends essentially on the carbon content and not on the special elements contained, provided these are kept within normal limits. The special elements, however, influence the facility with which the steel attains its maximum hardness. Thus the elements with the most hardening effects after carbon are nickel, chromium, molybdenum, and manganese. The effect of vanadium depends on the maximum temperature attained ; it has the tendency to produce coarse grain at high temperatures. Cobalt is the only element which has a softening effect. For good weldability, in the range of steels considered, the carbon content should not exceed 0·15%. The welding characteristics of a steel of 95 kg./sq. mm. ultimate strength and 10–12% elongation are given and its welding behaviour described.—M. D. J. B.

Welding Stainless Steels. (Aciers Fins et Spéciaux Français, 1950, Nov., pp. 47–49). Martensitic (12–18% Cr according to carbon content) and ferritic (Cr > 18%) steels may be arc welded using 18/8 austenitic steel electrodes. The following methods of welding austenitic steels are summarized briefly : (1) Oxy-acetylene, (2) electric arc, (3) atomic hydrogen, (4) inert atmosphere, and (5) resistance welding.—E. C. S.

Stainless Steel Fabrication for Aero Engines. (Welding, 1950, vol. 18, Sept., pp. 382–390). The " Sol-A-Die " method of sheet-metal forming by stage dies is described. Arc welding of titanium-stabilized and niobium-stabilized austenitic chromium–nickel steels is discussed. Jet-engine components are welded 50% by fusion and 50% by resistance. In many instances the quantities involved warrant a certain amount of special-purpose tooling. Illustrations are given for a number of welding assemblies.—U. E.

New Weldment Shop Adds Versatility. J. C. McComb. (Steel Processing, 1950, vol. 36, Dec., pp. 612–615, 630, 631). The author describes the plant and type of work carried out in the weldment division of the Continental Foundry and Machine Company's East Chicago works. Cable drum production from 1½ and ¾-in. steel plates by flame-cutting, forming and welding, and the fabrication of frames for 15-ton hydraulic presses, in 2¾ and 1-in. plate, are typical examples of the heavy jobs which can be undertaken. Photographs show most of the heavy equipment, which includes an Airco travograph and a Vernon 1000-ton press brake.—P. M. C.

Hard-Facing by Spray Welding. L. A. Holtgren and R. E. Parker. (Welding, 1950, vol. 18, Dec., pp. 523–528). Details are given of the technique developed for hard-facing special stainless steels which cannot be hard-faced satisfactorily by the normal procedures. The surface is cleaned by grit-blast, sprayed with hard-facing powder, and immediately fused by means of an oxy-acetylene torch. Parts should be cooled slowly and for certain alloys it is advisable to cool in the furnace at a rate of from 50 to 100° F./hr.—U. E.

Weldability of Steel K.52. J. Pilarczyk. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 321–329). [In Polish]. The types of steel used for welded constructions, the difficulties encountered in welding them, and efforts to determine their weldability are outlined.—V. G.

Photo-Elasticity an Aid to Welded Design. A. Swindells. (Welding, 1950, vol. 18, Oct., pp. 426–436). The author reviews the principles of photo-elasticity and its application to welded design problems. The general stress distribution and maximum shear stresses are determined on models. The method is to be regarded as complementary to experimental stress analysis by wire resistance strain gauges and by the brittle lacquer technique.—U. E.

Rationally Welded Construction as a Means of Economy. E. Sledziewski. (Hutnik, 1950, vol. 17, Nov.–Dec., pp. 434–438). [In Polish]. A brief discussion of welded construction and the possibilities of lowering its cost is given.—V. G.

Progress of Welding Technique in the U.S.S.R. Z. Lisowski. (Przeglad Techniczny, 1950, Nov., pp. 546–550). [In Polish]. A short historical survey of electric arc welding and an account of progress of welding technique in the U.S.S.R. are given.—V. G.

Dependence of Contraction and Distortion on Sequence of Welding Operations. W. Anders. (Die Technik, 1950, vol. 5, Sept., pp. 460–466). The distortion of welded parts depends to a large extent on the sequence in which individual seams are made. Data are quoted in tabular form on the distortion of single seams ; these were determined experimentally. The effect of clamping the work down or ' biassing ' the alignment of the parts to be welded was also studied. By these methods the dimensional changes of more complex parts, *e.g.*, the repair of a crankshaft, are studied, and recommendations as to the most effective sequence of operations are made.

Welded Power Plant. A Visit to W. H. Allen, Sons and Co., Ltd. (Welding, 1950, vol. 18, Sept., pp. 391–398 ; Oct., pp. 449–453). Welded steel designs as used in the production of marine and stationary power plant are described. A summary is given of a lecture by J. E. Willey and R. T. Rolfe on ' The Application of Electric Welding in General Engineering.' The first part deals with the design of welded structures and in the second part metallurgical properties are discussed. Examples are given of bend and tensile tests on welds.—U. E.

New Techniques Added to Pressure Welding. (Iron Age, 1950, vol. 166, Oct. 26, pp. 58–60). Some new types of cold welds have been developed by the Koldweld Corp., New York, which overcome objections to older methods. These include the use of inserts so that the joint can be pressed to a uniform thickness, the development of a staggered weld for joining thin sheets to bar stock, and improvements in the welding of dissimilar metals.—A. M. F.

Resistance Welding. R. Bushell. (Welding, 1950, vol. 18, Sept., pp. 372–381). The author summarizes a number of modern developments and resistance welding applications and illustrations are given of different welding machines.

Formulae for Obtaining Optimum Settings for the Spot Welding of Clean Mild Steel. R. W. Humpage and B. C. R. Burford. (Welding, 1950, vol. 18, Dec., pp. 515–522). The authors have attempted to derive formulæ for calculating welding settings which will produce the best results in low-carbon mild-steel sheet up to 0·25 in. thick. To obtain welding-machine variables formulæ are given for electrode tip diameter, electrode pressure, welding current, and welding time.—U. E.

Stud Welding with " Stored Energy "—Development of the Graham Process. K. S. Estlin. (Welding, 1950, vol. 18, Oct., pp. 446–448). The principle of the process lies in the discharge from a condenser of a predetermined quantity of energy to form an arc at the base of the stud created by means of an irregular tip which, on coming in contact with the work piece, fuses, causing ionization and in turn allows a path for the main discharge. Formation of the arc is immediately followed by a hammer blow of controlled speed and effort which, in conjunction with the melting of the adjacent surfaces, affects the welding operation. The Graham equipment is a self-contained unit requiring only the normal A.C. or D.C. mains supply and an air line with a pressure of 100 lb./sq. in.—U. E.

Welding in Relation to Castings. A. T. Batty. (Australasian Engineer, 1950, Dec. 7, pp. 69–73). The author describes, with examples, the following three distinct applications of welding : (1) The rectification of casting defects such as blow-holes, scabs, sand inclusions, and tears ; (2) the repair and reclamation of worn parts by hard facing ; and (3) the production of complex structures by welding together two or more separately cast components.—P. M. C.

Quality Control of Welding Work. W. Felix. (Sulzer Technical Review, 1950, No. 4, pp. 7–21). The weld testing methods employed by Sulzer Brothers are reviewed. These methods are applied not only to ensure the quality of welds but to keep a check on the ability and professional responsibility of each welder.—R. A. R.

Contribution to the Establishment of Consistent Methods of Interpreting X-Ray Photographs of Weld Seams. F. Wulff. (Die Technik, 1950, vol. 5, Nov., pp. 559–563). The author describes typical faults in copper and steel weld seams and examines their causes. He then points to the need for standardization of X-ray inspection. He proposes a classification of seams, *e.g.*, a class for all boiler seams and seams in bridge construction, which are loaded in tension. Special training of inspectors is recommended, and a numerical grading of faults should be undertaken. An inspection form used in the author's materials testing station at Halle is reproduced.—J. G. W.

Furnace Brazing of Machine Parts. H. M. Webber. (Mechanical Engineering, 1950, vol. 72, Nov., pp. 863–869 ; Dec., pp. 969–976). The fundamentals of furnace brazing are briefly discussed. Typical applications of electric furnace brazing to replace other methods of manufacture such as casting, machining, forging, and welding are given. One application is the bright brazing of high-chromium alloys without flux. Many practical methods of holding components for brazing during passage through the furnace are given and the best form and location of the brazing metal described. A brief outline is given of the available brazing metals. The author concludes with a survey of the various types of brazing furnace and protective atmosphere equipment. There are 16 references.—D. H.

Brazing by Induction. G. Gourod. (Métaux et Industries, 1950, No. 2, pp. 50–64). The author begins by explaining the principles of brazing and soldering by classical methods. The technique of induction heating is then described in some detail, including methods of joining very dissimilar pieces. The advantages are : Rapidity ; room is left between specimen and induction coil for a flux if one is needed ; heating is local thus preventing distortion when pressure is used, and facilitating clamping ; and highly skilled labour is not required. The behaviour of steel and other metals with various brazing materials is mentioned.—N. MCE.

Efficient Oxygen Cutting. Methods for Achieving Accurate Results. L. L. Arundel. (Welding, 1950, vol. 18, Sept., pp. 399–403 ; Oct., pp. 442–445). The process of cutting steel by oxygen depends on the fact that at high temperatures (about 900° C.) iron particles combine with oxygen to form the oxide Fe_3O_4. The oxygen stream having a fairly high velocity produces a scouring effect on the sides of the cut, therefore increasing the efficiency of the process. The influence of preheat on the accuracy is discussed and a comparison of available fuel gases is given. Permissible cutting tolerances for different classes of work are suggested.—U. E.

MACHINING AND MACHINABILITY

Hardened Steel Milled with Carbide. A. Ashburn. (Machinist, 1950, vol. 94, July 1, pp. 988–989). The author describes how dies hardened to Rockwell C62 are milled in routine operations at Parsons Tool Inc., Berlin, Conn. Drilling, boring, and counterboring are also carried out with the same ease. Thus, by cutting out the expense and time of annealing or grinding, dies can be quickly altered or repaired.—T. W. H.

The Effect of Manganese Segregations on Machinability. K. J. B. Wolfe and I. R. Robinson. (Metallurgia, 1951, vol. 43, Jan., pp. 3–7). An explanation of the variability in machinability of steels of apparently identical physical properties and composition has been sought in the presence of manganese-rich segregations, and demonstrated in many constructional steels by means of microradiography. Machinability determinations using drill-life tests indicate that these segregations, by their abrasive nature, increase drill wear, and, because of their shape and brittleness, reduce the force required to carry through the cutting operation. An estimate of the manganese content of the segregations is made and discussed in the light of the iron–manganese equilibrium diagram and transformation curves.—J. B. B.

Hot Machining of Many Metals Improved by Arc Heating. E. T. Armstrong and A. S. Cosler. (Materials and Methods, 1951, vol. 33, Jan., pp. 69–73). Metal cutting at elevated temperatures, using a new arc heating method, has been developed at the Battelle Memorial Institute (U.S.A.). Several materials, virtually unmachinable at ordinary temperatures, have been satisfactorily turned with standard carbide tools. These include a fully hardened high-speed steel, a deep-hardening Ni–Cr–Mo steel with high manganese content, Clarite (18% W, 4% Cr, 1¼% Va), Vitallium (25% Cr, 5% Mo, 70% Co), and two high-temperature alloys (20% Ni, 20% Cr, 20% Co + Mo–W–Cb). The effect of power density on the tool-life/cutting-speed relationship is shown. P. M. C.

The Vibration of Machine Tool Frames. A. Heiss. (VDI-Forschungsheft, 1949–50, vol. 16, No. 429). This is a monograph based on researches by H. Kiekebusch, H. Keltner, and A. Heiss during 1933–1944 ; it is concerned primarily with welded steel frames.—J. G. W.

Machinability Research Program Reported. (Iron Age, 1950, vol. 166, Nov. 9, pp. 99–102). This article reviews a report published by the Curtiss-Wright Corp., Wood-Ridge, N.J. The report starts with basic and complete analysis of machining conditions and covers tool design and selection, microstructures, evaluation of productivity of machine tools, and every variable in the highly complex problem of better machining of standard steels, jet-engine alloys, and cast irons. Dynamometers have been widely used to measure cutting forces, and cutting-edge temperatures have been carefully measured. The mechanical, physical, and machining characteristics of alloys are tabulated, and cast steel and flake and nodular graphitic irons are compared and reported on at length.—A. M. F.

CLEANING AND PICKLING

The Testing of Metallic Abrasives. R. V. Riley J. R. Park, and K. Southwick. (Institute of Vitreous Enamellers : Sheet Metal Industries, 1950, vol. 27, Nov.–Dec., pp. 955–967). Reference is made to the many and varied uses to which shot-blasting is now put. The constitution and physical constants of chilled iron shot and grit, heat-treated cast-iron and cast-steel abrasives, and hard-drawn steel pellets, are briefly outlined and tabulated. The mounting of these materials, and the procedure for hardness testing and metallographic examination are described. Several specially devised performance tests and typical results are discussed.—P. M. C.

Hard Drawn Steel Pellets for Cleaning and Peening. J. E. Hurst. (Foundry Trade Journal, 1951, vol. 90, Feb. 1, pp. 133–134). For cleaning purposes, the advantages claimed are long working life, slow breakdown rate, and the fact that the pellets can be manufactured in many ductile metals and alloys. The improvement in fatigue strength and endurance limit, produced by shot-peening of highly stressed machine parts, is also emphasized.—J. E. W.

British Hard-Drawn Steel Pellets for Cleaning and Peening. (Metallurgia, 1951, vol. 43, Feb., pp. 81–88). **Metal Abrasive Pellets.** (Metal Industry, 1951, vol. 78, Feb. 9, pp. 111, 112). This is a short account of the uses and advantages of the newly developed shot-peening material—hard-drawn steel pellets. The pellets are cut from wire having a tensile strength of 100–130 tons/sq. in., and a Brinell hardness between 400 and 500. Such pellets allow better process control and have many advantages over chilled cast-iron shot. These pellets are now made by Bradley and Foster, Ltd., Darlaston. P. M. C.

Industrial Electrolytic Polishing. R. Mondon. (Technique et Science Aeronautiques, 1949, No. 4, pp. 186–199). The present state of the development of electrolytic polishing in industry, and the future prospects of the process are discussed. The specially promising applications are to stainless steels and non-ferrous alloys. The treatment of highly stressed parts such as valve springs and valves, and of anti-friction surfaces is described.—J. J.

Electrolytic Polishing. (Pro-Metal, 1951, Apr., pp. 824–825). A short appreciation is made of electrolytic polishing from the point of view of industrial applications.—J. J.

New Developments of Electrolytic Polishing. H. E. Zentler-Gordon. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 3). Accepting the limitation that most metals now available, with the exception of stainless steel, are not completely satisfactory for electropolishing, the part that this process can play in finishing is discussed. Examples are quoted from French practice and relate to

polishing stainless-steel articles to produce an acceptable polish, the treatment of German silver and brass to enable them to be deep drawn with no, or with fewer, inter-pass anneals, and polishing reflectors made from specially processed aluminium. The work at present being carried out in France in applying electrolytic polishing to 'super-finished' steel internal-combustion-engine components to reduce friction, fatigue, and wear is described. The electrolytes used in all cases are of the sulphuric–phosphoric–chromic acid or phosphoric–chromic acid type.—J. P.

Polishing and Buffing. J. H. Lindsey. (Plating, 1950, vol. 37, Nov., pp. 1143–1148; Dec., pp. 1247–1254). This is a review of the literature on these subjects. A bibliography of 60 references is included.—J. P.

A Simple Instrument for Measuring "Surface Truth" of Metal Surfaces and the Amount of Polishing Required. G. E. Gardam. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 4). The instrument, which is designed to detect imperfections before polishing, consists of a vertical illuminated screen of alternate black and white stripes in two directions at right angles. The article to be examined is held squarely in front of the screen and moved so that the reflected image is seen by looking vertically downwards. The article is then slowly moved away from the screen until the black and white stripes can no longer be distinguished. The distance between the article and the screen is then a measure of the lack of surface truth and, when used for comparing similar objects, gives an indication of the amount of metal which must be removed before the surface is true and ready for polishing.—J. P.

Sulphuric Acid Cleaning and Coating of Rod and Wire in a Straightline Operation. R. H. Hertzog. (Wire and Wire Products, 1950, vol. 25, Dec., pp. 1047, 1048, 1079–1082). The author describes straight-line cleaning of rod and wire in sulphuric acid, as practised by John A. Roebling's Sons Company, Trenton, N.J. The cleaning shop contains loading rack, copper-coating tank, water rinse tank, four sulphuric acid cleaning tanks, water rinse tanks, pressure water spray tank, sull rack, two borax coating tanks, two lime coating tanks, drip rack, five Morrison flash bakers, and an unloading rack, in that order. Material is handled by two gantry cranes, one for acid, the other for coating. The acid tanks hold about 5200 gal. Cleaning and coating tanks are heated by live steam, borax tanks by closed steam coils; the flash bakers are oil-fired. Details are given of each solution, the change cycle, and the times of immersion. The capacity of the plant is 750,000–950,000 lb./24 hr., and raw acid consumption 29–40 lb./ton of material cleaned. Sull and borax coats are used for heavy dry drafting, borax for light dry drafting, lime coat for all finished spring wire down to 0·054 in. in dia., and copper coat for wet drawing of fine wire.—J. G. W.

The Investigation of the Efficiency of Various Methods of Removing Mineral Oil from Steel Surfaces. M. Smialowski, J. Foryst, and J. Madejski. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 55–63). [In Polish]. Different methods of removing mineral oil from steel surfaces are discussed and results of the authors' experiments described.
V. G.

Continuous Cascade Pickling. W. H. Stuck and J. H. Abrams. (Iron and Steel Engineer, 1951, vol. 28, Feb., pp. 101–108). This paper describes the new 42-in. continuous pickler at the Aliquippa works of the Jones and Laughlin Steel Corp. The installation embodies some entirely new improvements. The pickle line is in two major divisions, the entry and the delivery ends, separated by a looping pit. The entry end, following the sequence of operations, includes coil conveyors, scale breaker, up-cut shear, welder, flash trimmer, stitcher, and main pinch roll. The delivery end includes the pickling tanks, rinse tanks, and a dryer. No. 3 pinch roll is followed by an up-cut shear, trimmer, oiler, and coiler.
M. D. J. B.

Report on the Cleaning of Sheet Metal prior to Vitreous Enamelling. (Institute of Vitreous Enamellers: Sheet Metal Industries, 1951, vol. 28, Jan., pp. 89–94). This is a report of the Sheet Metal Cleaning Sub-Committee of the Institute of Vitreous Enamellers, presented at the 16th Annual Conference. An outline is given of the experimental work which has been carried out during the past few years, and the applications and operation of the following processes are described: Alkaline cleaning and degreasing, trichlorethylene degreasing, high-temperature grease burning, and acid scaling. The results of tests with phosphate coatings are also outlined.
P. M. C.

Maintenance in Pickling Shops. G. T. Dunkley. (Wire Industry, 1951, vol. 18, Feb., pp. 144–145). The atmosphere in pickling shops is exceptionally corrosive. The author reviews methods of protecting and maintaining the walls, floors, asbestos cement roof sheeting, pickling tanks, structural steel and cranes, fans, and ducting. He recommends acid-resisting paints in areas which are not subject to heavy traffic, and chlorinated rubber paint for structural steel in preference to bituminous paints on account of its longer life. A sprayed metal undercoat on new steelwork appears to increase the protective value of the paints.—J. G. W.

Chemically Applied Coatings for the Cold Drawing of Wire. J. F. Leland. (Wire and Wire Products, 1950, vol. 25, Dec., pp. 1049, 1082–1084). The author describes treatments developed by the Parker Rust Proof Co., Detroit. In one, Bonderite SS solution is applied for 3 min. to stainless steel wires after pickling; the wires are then rinsed in hot water and dried, after which they are ready to be drawn. Improved surface finish, 50–100% increase in drawing speeds, 50% increase in die performance, and easy removal are claimed for the coating. Experimental work at John A. Roebling's Sons Company with phosphate coating is showing considerable promise for low-carbon weaving wire and tyre bead wire. In this case pickling in H_2SO_4 or HCl is followed by water rinse, 1½–3 min. dip in Bonderite at 155° F., cold-water rinse, and 1 min. dip in a sealing solution at 160–180° F. The fine phosphate coating is chemically bonded to the wire surface, and being very absorbent it picks up the lubricant quite easily.—J. G. W.

Molten Salt Descaling. H. Clark Smith, jun. (Wire and Wire Products, 1950, vol. 25, Dec., pp. 1050–1051, 1085–1089). The author describes his experiences with the molten salt descaling plant installed by Wilbur B. Driver Co., Newark, New Jersey, six years ago. The Hooker or Virgo process is used. An oxidizing salt such as sodium nitrate or permanganate is added to the molten caustic soda. The scaled rods, wire, or strip, are immersed in the bath for 1–15 min., followed by a water quench. The Driver Company uses this plant for the descaling of electrical and heat-resistant high nickel–chromium alloys and austenitic stainless steels; the metal loss is about 1% and the surface white and slightly etched. The water quench is followed by 3–5 min. in hot HCl and an equal time in an unheated nitric-hydrofluoric mixture. The heating is by means of three rows of radiant cup gas burners firing at the side of the pot. Maintenance involves regular inspection of the pot for leaks and dragout of sludge. In the presence of suitable catalysts the bath preserves its action indefinitely. Attempts to use the treated scale as lubricant in the mill have not been conclusive. The acid pickle is essential to neutralize the caustic which causes abrasive action in the dies. The pickle is followed by liming and baking.—J. G. W.

"Emulsion" Cleaning of Metals. G. Schmerling. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 12). The theoretical basis of grease removal from metal surfaces by cleaners containing surface active agents is discussed. Experiments are described in which an emulsion cleaner was developed having good detergency for a wide range of soils and which was non-corrosive to metals and without effect on polyvinyl chloride and polythene (materials used for covering plating jigs). The following example is given: Pine oil, 62%; oleic acid, 10·8%; triethanolamine, 7·2%; ethylene, and glycol monobutyl ether, 20%. Before use, this is diluted with an equal volume of a 50/50 mixture of white spirit and solvent naphtha. The article to be cleaned is dipped in or coated with the cleaner and then rinsed or sprayed with cold water. Very little of the grease is dissolved in the cleaner; removal takes place when the cleaner is emulsified in the rinse water. The use of an emulsion of the cleaner in water as a single-stage detergent is described.—J. P.

Surface Active Agents in the Improvement of the Cleaning of Metals. R. C. Tarring. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 13). Wetting of metals, and constitution, mode of action, and application of surface active agents to improve aqueous cleaners are discussed. The uses of wetting agents to assist penetration and draining of pickling acid, and of foaming agents to reduce spray are described.—J. P.

XUM

Clad Steel Equipment—Some Hints for Modern Maintenance. E. H. Wyche. (Chemical Engineering, 1951, vol. 58, Jan., pp. 122–123). The care of stainless-clad and high-nickel-alloy-clad steel equipment, polished and unpolished, is described. It is essential to maintain the surfaces free from contamination if corrosion is to be avoided. Suitable cleaning methods are suggested.—T. E. D.

The Choice and Control of Cleaning Solutions. K. E. Langford. (Electroplating, 1951, vol. 4, Feb., pp. 41–44). It is suggested that aqueous alkaline cleaners should be compounded only from materials which can be analysed by titration when present together, and thus subjected to routine control. Methods are described for analysing mixtures of trisodium phosphate, sodium metasilicate, and sodium cyanide, of sodium hydroxide and sodium carbonate, and of sodium hydroxide and trisodium phosphate. Some formulations for various cleaning purposes are recommended.—J. P.

Disposal of Spent Liquor in Metal Pickling Shops. R. Freitag. (Metall, 1950, vol. 4, June, pp. 239–240). This is a brief survey of liquor disposal problems in metal pickling shops. The author points to the need for precipitation and removal of metal salts so as to avoid poisoning the biological sewage filters. Where large quantities of spent liquor are produced, recovery or conversion is worth while. This is the case with sulphate and chloride solutions.—J. G. W.

Industrial Preparation of Metallic Surfaces before the Application of Paint. H. Leclerc. (Peintures, Pigments, Vernis, 1950, vol. 26, Oct., pp. 405–409). The method of preparing the surface of a metal before painting is shown to be equally as important as the quality of the paint used. A summary is given of the methods of pretreatment in current use, such as sand-blasting, wire-brushing, degreasing by solvents, flame descaling, phosphatizing, etc. The treatment of ferrous and non-ferrous metals is described.—J. J.

Improved Radioactive Tracer Carrier for Metal Cleaning Studies. J. C. Harris, R. E. Kamp, and W. H. Yanko. (A.S.T.M. Bulletin, 1950, Dec., pp. 82–83). Work is described showing that a radioactive tracer consisting of an active carbon atom in N, N-di-*n*-butyl stearamide may be used with good results to study the effectiveness of metal-cleaning methods.—J. J.

Detection of Soil Removal in Metal Cleaning by the Radioactive Tracer Technique. J. C. Harris, R. E. Kamp, and W. H. Yanko. (Journal of the Electrochemical Society, 1950, vol. 97, Dec., pp. 430–432). Various qualitative tests have been described for determining the cleanliness of a metallic surface after degreasing treatments, but it was not known how sensitive these tests were. Using a radioactive tracer technique, not described, it was shown that for a soil consisting of lubricating oil, fluorescent dye, and dibutylstearamide, the various methods of determination of cleanliness cease to function between the following limits: Fluorescent dye, 2×10^{-5} to 6×10^{-6}; copper immersion deposit, 6×10^{-6} to 2×10^{-6}; water break, 2×10^{-6} to 4×10^{-7}; radioactive tracer, 2×10^{-7} to 0·0 g./sq. cm. of soil.—J. P.

Development of Metal Cleaners Using Radioisotopic Evaluation Methods. J. C. Harris and R. E. Kamp. (Metal Finishing, 1950, vol. 48, Nov., pp. 75–78). Geiger-Müller counts of standard steel discs, coated with an oily soil containing 'C^{14}-tagged' undecane and subjected to various immersion cleaning treatments are used to evaluate the efficiency of these treatments. A relatively non-foaming composition consisting of 2·5% of polyethylene oxide condensate and 97·5% sodium metasilicate performed at least as satisfactorily as the better known foaming composition of 5% alkylbenzene sulphonate and 95% metasilicate. Of the various alkali types used, in conjunction with dodecylbenzene sodium sulphonate, the meta- and orthosilicates proved most effective, a second but lower level of effectiveness was attained with soda ash, trisodium phosphate, and tetrasodium pyrophosphate, while still lower in soil removal efficiency were modified soda and caustic soda.—J. P.

PROTECTIVE COATINGS

Throwing Power in Alloy Deposition. J. W. Cuthbertson. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, pp. 81–83). When depositing a single metal it is necessary only to ensure a good thickness distribution over the article, but with alloy plating it is also necessary to ensure uniformity of composition and this may be an added difficulty. On irregular articles, speculum plating may be unsatisfactory because the Sn/Cu ratio in the deposit is not everywhere in the rather narrow bright range. Alkaline tin–zinc solutions, however, have good thickness and throwing power. Another difficulty is encountered in alloy plating when the nature of the base metal is such that one component of the alloy is deposited only with difficulty, *e.g.*, attempts to plate brass on cold-rolled mild steel sometimes result in the deposition of copper only, although when the steel is annealed, brass will plate satisfactorily.—J. P.

Practical Implications of Throwing Power. S. Wernick. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, pp. 83–92). The impossibility of obtaining minimum specified nickel thicknesses on recessed parts of components without excessive deposits on other parts is stressed. Collaboration between designer and plater is called for to rule out shapes which cannot be properly plated to such specifications. Some hints are given on obtaining the best distribution in certain instances.—J. P.

Effect of Impurities and Purification of Electroplating Solutions. I—Nickel Solutions. (4) The Effects and Removal of Copper. D. T. Ewing, R. J. Rominski, and W. M. King. (Plating, 1950, vol. 37, Nov., pp. 1157–1160). Ten mg. per litre of dissolved copper cause a loss of lustre in the cobalt and organic addition types of bright nickel deposit, a loss of ductility, a 20% loss of salt-spray corrosion resistance, and a loss of throwing power in Watts nickel solutions. As the concentration of copper increases, there are further losses in lustre of the bright deposits and darkening of the Watts deposits, and of ductility of all deposits, a significant increase in hardness of Watts deposits and a further reduction in corrosion resistance. At 100 mg. of copper per litre, the deposits become unusable for all practical purposes. Copper can be removed electrolytically, optimum current density being 1–2 amp./sq. ft. Increase of temperature and vigorous agitation of the solution increases the amount of copper removed. Copper can also be reduced by high *p*H treatment with $NiCO_3$ to a minimum of 15 mg./litre.—J. P.

Porosity of Electrodeposited Metals. Part VII—Rates of Corrosion of Protectively Plated Iron Foils: Part VIII—Loss of Weight, Increase of Permeability and Failure of Electrodeposited Coatings: Part IX—Effect of Certain Aromatic Polysulphonates on the Permeability and Corrodibility of Electrodeposited Nickel Foils. N. Thon, L. Yang, and D. Kelemen. (Plating, 1950, vol. 37, June, pp. 631–632: July, pp. 749–752, 752–753). In Part VII the rates of corrosion of electrolytic iron foils, plated with copper, nickel, and chromium, with nickel and chromium, with copper and nickel, and with nickel alone, when immersed in distilled water(*p*H 5·4 at 95° C.) assessed by a gas permeability test are reported. The results indicate that lowest rates of corrosion are obtained with the ternary coating, particularly when the nickel is thick. Of the bimetallic coatings, the nickel + chromium was better than the copper + nickel. Coatings containing bright nickel were inferior to the corresponding ones containing a Watts nickel layer. Part VIII describes experiments on nickel foils of different thicknesses exposed to a corrosive environment showing that although all corrode at the same rate as judged by loss of weight, the rate of increase of permeability depends on thickness. Similarly, the time to ultimate visible failure, *i.e.*, perforation, depends on thickness and thus 'life' can be predicted from the increase of permeability in the early stages of corrosion before any measurable corrosion has occurred. Electrodeposited iron coated with a given thickness of nickel has a longer life than rolled iron similarly coated. Nickel coatings on smooth metals have higher permeabilities than those on etched or freshly deposited metals. Corrosion through nickel coatings thus occurs only when there has been considerable penetration of the coating and not merely at the site of initial pores. Corrosion of the basis metal, at a particular spot is not to be ascribed to initial porosity of the coating in the usually accepted sense but to the fact that for some reason the coating was more corrodible there; this may be caused by the local characteristics of the basis metal. In Part IX it is shown that the initial permeability of thin films of nickel deposited from a Watts bath is increased when sufficient of the following are added to give a bright plate: (I) Nickel *m*-benzene-disulphonate, (II) sodium naphthalene-1 : 5-disulphonate, (III) 1-naphthylamine-4 : 8-disulphonic acid, and (IV) 1-naphthylamine-3 : 6 : 8-trisulphonic acid.—J. P.

Some Applications of Interferometry to the Examination of an Electrodeposited Film. S. Tolansky. (Journal of the Electrodepositors' Technical Society, 1951, vol. 27, Advance Copy No. 6). By means of multiple beam interferometry, it is shown that work-hardening and distortion around a hardness micro-indentation extends to almost three times the diagonal of the indentation. With an anisotropic material, such as a single crystal of tin, the extent of distortion is considerably greater than two and a half times the diagonal, indicating that the British Standard requirement for spacing of indents is not adequate. Illustrations are reproduced to show how the thickness of very thin films can be measured with great accuracy and how a bright tin–nickel deposit 0·00022 in. thick faithfully follows the contour of the basis metal. Microhardness measurements have indicated that considerable discretion must be used in attempting to interpret them on surfaces which have continuous hardness variation in depth, as occurs in case-hardening, and possibly also in polishing processes.—J. P.

Studies in the Discontinuities of Electrodeposited Metallic Coatings. III. S. C. Shome and U. R. Evans. (Journal of the Electrodepositors' Technical Society, 1951, vol. 27, Advance Copy No. 1A). The theoretical principles underlying porosity tests for cathodic coatings on steel are discussed. The reagent should not attack the coating, should be highly conducting, and should contain a cathodic stimulator. The ferroxyl, hot water, and salt-spray tests do not fulfil these conditions, but aqueous 3% NaCl containing 1·5 vol.-% of 20 vol.-% H_2O_2 is satisfactory. Rust spots appear quickly at pores because the H_2O_2 stimulates the cathodic reaction and so accelerates the solution of iron and simultaneously converts the ferrous ions to rust. There is less attack on nickel than with the ferroxyl test. The potential of nickel-plated steel moves in the cathodic direction as thickness of coating is increased, *i.e.*, as pore area diminishes. The movement is small in NaCl or ferroxyl solutions but marked if the NaCl solution contains H_2O_2.—J. P.

Studies in the Discontinuities in Electrodeposited Metallic Coatings. U. R. Evans and S. C. Shome. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 9). The work described relates mainly to nickel coatings on mild steel and iron. The porosity of thin electrodeposits was tested by the ferroxyl method. The results suggest that neither hydrogen bubbles nor impurities on the surface of the cathode can be the main source of pores. The most important cause of porosity appears to be the finish of the base metal, surface roughness tending to produce pores. Changes of current density and *p*H in nickel baths did not influence the number of pores in a deposit, but a rise in temperature increased the number. Attempts to produce pore-free composite coatings of nickel and copper, cobalt and nickel, and cobalt and chromium were unsuccessful.—J. P.

The Measurement of Throwing Power and the Prediction of Thickness Distribution. G. E. Gardam. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, pp. 77–81). It is shown that the throwing power as measured by the Haring-Blum test is only indicative of results likely to be obtained in practical plating, since the results it gives depend upon the size of the apparatus. There is no method by which a solution can be characterized in such a way that the plating thickness on an article can be predicted.—J. P.

The Economic and Other Advantages of Metal Rectifiers for the Electroplating Industry. F. G. Furniss. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, pp. 95–104). A comparison is made between metal rectifier and motor generator sets with respect to installation, maintenance, control, and operating costs under a variety of industrial conditions. This indicates the superiority of the metal rectifier.—J. P.

Adsorbed and Reaction Product Films on Metals. H. H. Uhlig. (Journal of the Electrochemical Society, 1950, vol. 97, Nov., pp. 215c–220c). After indicating the difference between physical and activated adsorption, the importance of the latter in explaining the passivity of iron, chromium, and stainless steels is discussed. The specific effect of chloride ions and cathodic hydrogen in breaking down passivity may be explained as a phenomenon of preferential adsorption. The rôle of oxygen as a passivator is due to its being chemisorbed; the relationship between work function and heat of sublimation as a criterion of passivity or reaction is illustrated by numerous examples. Metals can also be adsorbed on metals and in this way change very markedly their physical and chemical properties. This leads to a consideration of the possible effect of bringing a metal such as iron into intimate contact with chromium. When this is done, either by evaporation or electrodeposition, it is possible to dissolve away the massive metal in 3*N* HNO_3, yet leaving behind a unimolecular film of highly resistant iron on the chromium surface. It is suggested that this confirms the theory that passivity is related to electron interaction between the two metals. The corrosion resistance of a number of alloys appears to depend on chemical passivity, *i.e.*, the presence of chemisorbed films.—J. P.

Electrodeposition of Metal Powders. G. Wranglen. (Journal of the Electrochemical Society, 1950, vol. 97, Nov., pp. 353–360). Metal powders may be produced electrolytically by two different methods: (*a*) Direct deposition on the cathode, and (*b*) grinding of a brittle deposit. The principles underlying method (*a*) are dealt with. Three factors are shown to be responsible for the formation of powdery or spongy deposits: (1) Low metal overvoltage, (2) depletion of the cation content of the cathode film, and (3) hydroxide formation at the cathode. These factors may operate together or singly according to the conditions of electrolysis. The formation of copper, iron, nickel, zinc, and cadmium powders is described.—J. P.

The Thermodynamics of the Production of Metallic Coatings on Metals from Gaseous Metal Chlorides. T. P. Hoar and E. A. G. Croom. (Australian Institute of Metals: Australasian Engineer, 1950, Dec. 7, pp. 56–59). The thermodynamic data of metal chlorides have been collected and used to elucidate the mechanisms of the reactions involved in the 'chromizing,' 'siliconizing,' and 'stannizing' of metals in atmospheres containing volatile metal chlorides. Chromizing of iron can proceed partly by the interchange reaction $CrCl_2 + Fe \rightarrow Cr + FeCl_2$ and partly by the catalytic reduction $CrCl_2 + H_2 \rightarrow Cr + 2HCl$. Siliconizing of iron proceeds by interchange in a nitrogen–silicon tetrachloride atmosphere, and partly by reduction if hydrogen is present, while chromizing of nickel and molybdenum and stannizing of copper, possible only with hydrogen present, proceed entirely by catalytic reduction. P. M. C.

Progress in Metal Finishing Since 1929. S. Wernick. (Metallurgia, 1950, vol. 42, Nov., pp. 339–344). Progress in metal finishing during the last 21 years is reviewed under the following headings: Bright nickel and chromium plating; electroplating plants; control equipment; paints; chromating treatments; tinplating; protective plating with zinc and cadmium; heavy nickel plating; hard chromium; and electrolytic polishing.—J. B. B.

Heavy Nickel Plating for Salvage for Corrosion Resistance. P. J. Ritzenthaler. (Iron Age, 1950, vol. 165, Apr. 6, pp. 99–101). The use of heavy nickel plating for repairing machine parts, for example, undersize liners or oversize bores, is described. Four principal baths are in use, making it possible to deposit material in a range from 150 to 350–450 Brinell with tensile strengths from 22·3 to 66·9 tons/sq. in. Heavy nickel coatings offer excellent corrosion resistance and can be applied only where protection is necessary: a cast-iron beer pump, nickel-clad on the inside, is illustrated. Another plating application described is that of tin–lead plating a stainless-steel sleeve which rides up and down in contact with another stainless-steel part.—J. P. S.

Grain Size and Hardness of Nickel Plate as Related to Brightness. H. J. Read and R. Weil. (Plating, 1950, vol. 37, Dec., pp. 1257–1261). Measurements of grain size and hardness, and examination of surface structure by the electron microscope of nickel deposited from baths containing various additions agents have shown that there is no correlation between the brightness and grain size and hardness. Although there is a very broad general trend which indicates that brightness increases with decreasing grain size and increasing hardness, the specific exceptions are so numerous that they become more important than the general trend.—J. P.

Nickel Plating from Fluoborate Solutions. C. Struyk and A. E. Carlson. (Plating, 1950, vol. 37, Dec., pp. 1242–1246, 1263, 1264). The method of preparing fluoborate nickel baths is described. Results obtained with solutions of the following compositions: $Ni(BF_4)_2$ 220, 300, and 440 g., free HBF_4 4–38 g., free HBO_3 30 g./litre, *p*H 2·0–3·5, temperature 100–170° F., have shown that they possess the following advantages: (1) Control is simple, involving only a density

reading and a *p*H measurement. (2) Deposits are light in colour, smooth, and exhibit some lustre over a wide range of current density. (3) The solutions are more highly buffered than the sulphate or chloride baths and are thus more resistant to *p*H change. (4) Anode performance is excellent over a wide range of operating conditions. (5) The solutions have a relatively high tolerance for metallic impurities. (6) The conductivity is higher than that of the Watts-type bath and about equal to that of the all-chloride type. (7) $Ni(BF_4)_2$ has a high solubility, which is of advantage when high plating rates are required. (8) The solutions are stable and substantially free from sludging. (9) The internal stress in deposits from these solutions is lower than in those from Watts, and much lower than in those from chloride solutions. (10) The throwing power is improved by additions of NH_4BF_4. J. P.

Nickel Immersion Coatings by Electrochemical Displacement and by Chemical Reduction. W. A. Wesley. (Plating, 1950, vol. 37, July, pp. 732–734, 756). The production and properties of two non-electrolytic nickel coatings are reviewed. The displacement process, in which iron dissolves in a suitable solution and deposits an equivalent amount of nickel, can be used to produce only thin coatings, less than $50 \cdot 10^{-6}$ in. thick on an iron or steel base. They are thus not useful for decorative purposes, and they require heat-treatment to render them adherent. The 'nickelized' steel is suggested as an inexpensive superior base for vitreous enamelling, organic finishes, phosphatizing, and perhaps other metallic coats. The chemical reduction or 'electroless' process, in which the reduction of nickel solutions by sodium hypophosphite is catalysed by certain metallic surfaces, can be used to apply thick coatings on steel, copper, brass, aluminium, and nickel. The deposits are of good quality and protect against corrosion. Due to the costliness of the reducing agent, and its low efficiency, 'electroless' coatings can compete with electroplated nickel only for special purposes.—J. P.

The Electrodeposition of Tin from Stannous Fluoborate Baths. N. Parkinson. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 10). Previous work on fluoborate tin baths is briefly reviewed, and plating tests in a Hull cell on newly developed solutions are described. The best solution had the following composition per litre: Tin 80 g., gelatin 6 g., β-naphthol 1 g., and free HBF_4 150 g. This solution gave an excellent smooth white plate at current densities from 5 to 120 amp./sq. ft. at room temperature. At 40° C., the upper current density limit was about 250 amp./sq. ft. and the lower limit was also raised; throwing power decreased with rise in temperature. The bath was very stable and since anode and cathode efficiencies were both approximately 100%, the only additions required to the bath are occasional small amounts of gelatin and β-naphthol, as and when indicated by Hull cell tests. Similar solutions containing 0·6 g./litre of 4 : 4′-dihydroxydiphenylmethane or 3 g./litre of 4 : 4′-dihydroxydiphenylsulphone gave good results up to 100 amp./sq. ft., although the throwing power of the latter bath was not so good as the two others. Using these solutions it is possible to deposit 0·001 in. of tin in 4½ min. Advice is given on the preparation of the solution, and material for tanks. Sludging of the anodes occurs when the HBF_4 used for making up the solutions contains H_2SiF_6. Silica-free HBF_4 would probably be unduly costly so that resort must be had to bagging of the anodes. Terylene is the only material recommended for this purpose.—J. P.

Electrolytically Tinned Cold Rolled Strip. V. Seul and R. Mintrop. (Stahl und Eisen, 1950, vol. 70, Dec. 7, pp. 1154–1164). Modern methods of production of electrotinplate are reviewed. It is claimed that retraction of tin during flow-brightening can be reduced by subjecting the as-plated strip to a heat-treatment at a temperature just below the melting point of tin, immediately before the melting process. This is intended to drive off occluded hydrogen and dehydrate any plating salts left in interstices in the coating. Experiments which show that pickling inhibitors are not readily removed by rinsing in cold water indicate that more effective methods of cleaning are necessary if invisible adsorbed films are to be prevented from interfering with the production of good coatings.—J. P.

Sprayed Aluminium Coatings on Steel. G. Tolley. (Industrial Finishing, 1950, vol. 3, Dec., pp. 377–384). It is shown that aluminium coating on steel would be anodic to steel, and in all solutions of *p*H greater than 3, or containing less than a certain minimum quantity of aluminium ions, the coating would be initially cathodic, but after a short period a reversal of potential occurs. Attention is drawn to the use of sprayed aluminium as an undercoat for paint. Many aluminium alloys have poor resistance to sea water, but if pure aluminium is used as a coating upon steel a high degree of protection is conferred. Heat-treatment of aluminium-sprayed steel by holding at a temperature of 850–900° C. for 15 min. produces a complex coating, of which the inner solid solution layer provides the heat resistance, and heat-treatment is carried out to produce this layer.—E. T. T.

The Electrodeposition of Tin–Cadmium Alloys. P. S. Bennett. (Journal of the Electrodepositors' Technical Society, 1950, vol. 26, Advance Copy No. 6). It has been shown that tin and cadmium can be co-deposited from acid solutions of their sulphates provided that suitable addition agents are present. The tin content may be varied from 5 to 95% for mat and 7 to 35% for bright deposits. The following basic solution is recommended: Cadmium 30, tin 8, free H_2SO_4 50 g./litre. The tin content of the solution is adjusted to give the desired tin content in the deposit, and anodes of the same composition as the deposit are employed. The recommended current density is 25–30 amp./sq. ft. and 0·001 in. is then deposited in 20–25 min. The following additions are made per litre of solution: For mat plate, 1 g. of pentaerythritol and 0·2 to 1·0 g. of polyvinyl alcohol; for semi-bright plate, 50 g. of crude cresolsulphonic acid and 1 g. of dihydroxydiphenylmethane after reducing the free H_2SO_4 to 15–20 g./litre; for bright plate, 1 g. of saponine, 2 g. of Dreft, 4 g. of 2-naphthol-6-sulphonic acid, all dissolved in water, and then 1–2 g. of dihydroxydiphenyl methane in alcohol.—J. P.

Electrodeposition of Thalium and Thalium–Lead Alloys. E. Bertorelle, L. Giuffrè, and A. Tunesi. (Chimica e l'Industria, 1950, vol. 32, Nov., pp. 517–522). [In Italian]. This paper describes the results obtained by electrolysing fluoborate solutions of thalium containing a measure of free acidity and certain organic substances. With these solutions it is possible to electrodeposit thalium in a compact form and in fairly large thicknesses. On the basis of the electrochemical characteristics of thalium and lead deposits from fluoborate solutions the best conditions are established for their electrodeposition. M. D. J. B.

Plastics for Protective Coatings and Linings of Chemical Plant. E. E. Halls. (Metallurgia, 1950, vol. 42, Dec., pp. 376–381). The uses and limitations of various plastics for protective coatings and linings of chemical plant are described, together with methods of applying them, such as hot spraying, dipping, and lining with sheet.—J. B. B.

Time, Labor, and Materials Saved by Hot Spraying Industrial Organic Finishes. L. M. Garoff. (Materials and Methods, 1950, vol. 32, Dec., pp. 54–56). The hot spray process depends upon the effect of heat rather than the addition of thinners to reduce lacquers and synthetic enamels to spraying viscosity. Mixtures can thus contain more film-forming ingredients, and the results of comparative tests show that the hot process has the following advantages: Fewer coats are needed because the thickness of each is greater; solvent waste is lower; coverage per gallon is increased; capacity of plant is increased, and 'sagging,' 'blushing,' and the 'orange peel' effect are all less pronounced than in the cold-spraying process.—P. M. C.

Electrodeposits as Bases for Paints. H. Silman and Dorothy Wernick. (Journal of the Electrodepositors' Technical Society, 1950, vol. 25, pp. 175–188). Salt-spray and outdoor exposure tests have been conducted on mild-steel panels, electroplated with tin and zinc to different thicknesses and then finished with various paint and lacquer schemes. Some panels, to serve as controls, had no metallic undercoat or were phosphatized, and on others the electrodeposit was treated by phosphatizing or chromating. The results showed that, in general, pre-plated steel offers very considerable advantages over ordinary steel sheet and strip for painted articles to be subjected to severe conditions of service.—J. P.

The Vila Method for Short Period Testing of Antirust Coatings Compared with the Salt Spray and the Tropical Cabinet Methods. S. Köhler and K. Laurell. (Statens Provningsanstalt, 1949, Report No. 106). [In Swedish]. The protective value of four paint schemes on steel plates was assessed and compared using the Vila short-time corrosion testing apparatus. The paint schemes were: (*A*) Asphalt varnish; (*B*) red lead plus zinc oxide; (*C*) red lead plus

micaceous iron ore and aluminium : and (*D*) red lead plus plastic paint. In the Vila apparatus the specimens were subjected to the following cycle of conditions : (1) Washing in running water (30 min.) ; (2) cooling to − 8° C. (10 min.) ; (3) air containing 2 vol.-% SO_2 (95 min.) ; (4) heating to 80° C. with steam and cooling in water, repeated four times (total 80 min.) ; (5) complete immersion in salt water (115 min.) ; (6) washing in water (5 min.) ; (7) holding in a stream of air containing SO_2 while at a temperature of 50–60° C. (15 min.) ; (8) heating to 80° C. in steam (55 min.) ; (9) cooling in water (5 min.) ; and (10) half the length immersed in salt water (14½ hr.). This whole cycle was repeated for 25 days. In other tests some of the above conditions were omitted. In the full series coatings *A* showed much greater resistance than the others, the order of merit being *A*, *C*, *D*, and *B*. Warm air containing SO_2 had a predominating effect on schemes *B*, *C*, and *D*, the other conditions having very little effect. The Vila test appears to be effective in grading paints of one type, but the salt-spray test, which is much cheaper, is more suitable for comparing paints of different types. Paint coatings easily affected by water can be tested in a reasonably short time in a 'tropical cabinet' but it would take a very long time to test more permanent paints in this way.—R. A. R.

Titanium and Titanium Nitride Treatment of Steel. R. Skorski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 290–298). [In Polish]. An electrolytic method of forming a titanium surface on steel was tried with negative results. As an electrolyte, aqueous solutions of titanium iodide, tetra-iodide, and phosphate were used. Cementation with powdered titanium and titanium nitride also gave unsatisfactory results. Good surface coatings were obtained by heating steel samples in a fused mixture of titanium oxide, sodium carbonate, and sodium hydroxide at temperatures between 880 and 920° C. Similarly good surface coatings of titanium nitride on steel were obtained by immersion in a fused mixture of titanium oxide and sodium cyanide. The resistance to corrosion of titanium nitride coated steel was tested under conditions of tropical humidity and sea water. After twelve months no traces of corrosion were found. Bend tests on titanium-treated steel wire showed an increase in strength. Microphotographs of titanium-treated surfaces, percentage composition of mixtures used for titanium treatment, and chemical composition of the steels are given.—V. G.

POWDER METALLURGY

The Sintering of Iron. M. Eudier. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 825–834). The factors affecting the density and strength of the compressed powder and the hardness density and strength of the sintered powder are investigated. These include shape and size distribution of the grains, the force and speed of compression, and temperature and time of sintering. After compression at 6·5 tons/sq. cm. and sintering for 15 min. a pure iron sinter has a tensile strength of 19 kg./sq. mm., elongation 3%, Rockwell hardness 55, and density 6·7.—A. G.

The Determination by a Photo-Elastic Method of the Shape of a Tensile Test Piece for Sintered Materials. J. Aubaud. (Recherche Aéronautique, 1950, No. 17, pp. 33–36). A study was made by means of the photo-elastic effects of light passing through plastic materials of the best shape for a tensile test piece of sintered materials. In such materials it is not possible to use the classical forms of test pieces, since the crushing effects of the jaws used, or the local strain in a perforated sample, cause damage in the material which is frequently not sufficiently strong to resist such stresses. The Mesnager 'diabolo' shaped specimen designed for cement testing was found not to have a sufficiently well defined stress field at the point of rupture. A rational shape was developed which has been proved satisfactory in use.—J. J.

The Preparation of Hard Metals by the Impregnation Method. R. Kieffer and F. Kölbl. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Mar., pp. 49–58). After a short historical review the preparation of WC–Co and WC–TiC–Co alloys corresponding in composition to the standard specifications G1, G2, G3, S1, S2, and S3 by the impregnation of a carbide matrix with cobalt or WC–Co alloys is described. The hardness, structure, and tensile strength of the alloys so prepared are compared with those of standard materials. These properties are poorer in alloys containing little cobalt, but alloys containing more than 10% of cobalt have properties almost the same as those of corresponding alloys prepared by standard methods. TiC and TiC–Mo_2C-containing alloys were prepared by impregnation of the carbides by Ni–Cr, Co–Cr or Co–Cr–Mo alloys. Their hardness and heat-resistant properties were investigated. It is concluded that these alloys may be useful for use at high temperatures, *e.g.*, for gas-turbine blades.—O. H. G.

Ingot and Sinter Compact. R. Mitsche and E.-M. Onitsch. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Mar., pp. 61–64). A general comparison of casting and sintering processes in terms of the physical structure of the metal is made. There are 15 references.—O. H. G.

Sintered Manganese Steels. F. Benesovsky and R. Kieffer. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1950, vol. 95, Aug., pp. 145–150). The authors review the powder-metallurgical methods that may be used to manufacture steels containing from 2 to 16% of manganese and 0·2 to 1·6% of carbon. There are 22 references.—O. H. G.

Considerations in Designing Tools for Powder Metallurgy. I. J. Donahue. (Mechanical Engineering, 1950, vol. 72, Nov., pp. 886–889). Factors affecting the design of tools for use in the pressing of metal-powder parts are discussed. The types of tool used in the making of simple and flanged bushings are described.—D. H.

Twenty-One Years of Powder Metallurgy. H. W. Greenwood. (Metallurgia, 1950, vol. 42, Nov., pp. 336–338). The growth of powder metallurgy from its infancy 21 years ago to its present position, in which it offers the unique solution to quite a number of major metallurgical and engineering problems, is reviewed.—J. B. B.

PROPERTIES AND TESTS

Behaviour of Constructional Materials under Rapidly Changing Stresses. W. Weibull. (Blad för Bergshandteringens Vänner, 1947–48, No. 3, pp. 97–116). [In Swedish]. Speed of stretching has no influence below the elastic limit, and above this limit the tensile strength increases with the logarithm of the speed of stretching. Around the elastic limit a discontinuous decrease in the tensile strength occurs even at constant or slowly increased strain. The speed of stretching influences the upper as well as the lower elastic limit. Miklowitz, Elam, and Welter have found that this holds for soft silicon steels. The author criticizes these results and maintains that the upper and the lower elastic limit increase equally with increased speed of stretching, as confirmed by experiments with a very rigid testing machine. Finally, some statistical aspects of fatigue tests are presented. B. S. E.

An Ingenious Universal Testing Machine. L. Sanderson. (British Steelmaker, 1951, vol. 17, Feb., pp. 101–104). A detailed description is given of a new universal testing machine in which the weighing system comprises a load-indicating contrivance on the principle of the pendulum lever. This dependence on simple mechanical laws is claimed to combine accuracy, simplicity, and freedom from many of the drawbacks associated with the more usual hydraulic or spring weighing mechanisms. The machine, made by Tinius Olsen Testing Machine Co., Philadelphia, has three dual-scale ranges, and accuracy is guaranteed to be within 0·5% above one-fifth capacity on any load range.—G. F.

Testing Machine for Combined Tension and Torsion. H. V. Pollard and H. J. Tapsell. (National Physical Laboratory : Engineering, 1951, vol. 171, Jan. 12, pp. 58–59). A description is given of a machine constructed for the purpose of studying the problem of plastic flow of materials at high temperatures under time-independent conditions. The machine developed at the National Physical Laboratory can be used for carrying out tests on specimens under tension, torsion, tension with any fixed static torsion, torsion with any fixed static tension, or with the ratio of tensile load to twisting moment remaining constant throughout the test at any desired value from 0·2 to 10.—M. D. J. B.

Stress Analysis Using the Brittle Lacquer Process. K. C. Rockey. (Transactions of the Institute of Marine Engineers, 1951, vol. 63, Mar., pp. 43–54). The paper describes the brittle lacquer process of stress analysis, which enables both qualitative and quantitative results to be obtained. It provides a comprehensive picture of the stress distribution

existing in a member under load, since the lacquer develops a series of cracks which lie normal to the principal tensile stresses, the intensity of these cracks being dependent upon the value of the strain. The lacquers, which can be used on members of any size, are capable of recording load impulses of very short time interval. A chronological review is made of the development of this process as a tool of the stress analyst. The properties, limitations, and methods of application of the various lacquers available today are dealt with in detail. Finally, the author gives the results he has obtained by heat-treating two different lacquers. It is shown that by suitable heat-treatment a very high degree of sensitivity to strain is obtained. A number of photographs illustrate the results obtained with these heat-treated lacquers.—D. H.

Photoelastic Determination of Stresses in a Perforated Beam. A. Mondina. (Costruzioni Metalliche, 1951, vol. 3, Jan.–Feb., pp. 8–12). [In Italian]. This paper gives the results of investigations carried out on a freely supported beam with a circular hole drilled in the middle. In the model described the load was applied in the hole, thus reproducing the stress distribution frequently encountered in lever arms and in numerous machine parts. A comparison is made between the experimental results obtained and analytical computations.—M. D. J. B.

Photoelastic Study of Stresses on Matthaes Samples for Stress Corrosion Experiments. W. Ruff. (Alluminio, 1950, vol. 19, No. 5, pp. 411–415). [In Italian]. The author investigates, by photoelastic methods, the stress distribution in Matthaes test pieces under tension. The values for the factors giving stress concentration agree very closely with those obtained by direct extensometer measurements carried out in previous tests on a model in Superavional D alloy submitted to compression.—M. D. J. B.

Improvements in Photoelastic Measuring Equipment. W. Ruff. (Alluminio, 1950, vol. 19, No. 6, pp. 523–536). [In Italian]. A description is given of modifications carried out on a 1939 model Winkell-Zeiss photoelastic measuring equipment. It is claimed that these modifications enable greater accuracy to be obtained in photoelastic methods of stress analysis.—M. D. J. B.

Static Extensometry on Short and Very Short Base Lengths. H. de Leiris. (Machinist, 1950, vol. 94, July, pp. 973–978; Aug. 5, pp. 1131–1136). The author briefly summarizes the principle of measuring stress, explains how direct measurement of strains can be carried out with electrical resistance strain gauges, and indicates the possible sources of error when such gauges are used over a short gauge length. He reviews the technique of extensometry on bases of the order of 20 mm. and 2 mm. He claims that its possibilities in experimental stress analysis are manifold, and in some respects unrivalled, although there are limitations. Very short base extensometers, in particular, permit operations in ranges, or with magnifications which would be impracticable by other known methods for the degree of accuracy required. The essential constructional features of these short and very short base extensometers are described, and the technique and formulæ used in their application are discussed.—T. W. H.

The Importance of Sensitivity to Brittle Fracture in the Welding of Structural Steels. W. Grosse. (Stahl und Eisen, 1950, vol. 70, Dec. 21, pp. 1193–1204). The suitability of steel for structural purposes is not adequately assessed by tensile and bending tests. Sensitivity to brittle fracture is a property of the material and it is therefore wrong to characterize a brittle failure by the particular fabrication process which induces it. Of the many different procedures for testing for sensitivity to embrittlement, that proposed by Schnadt is described most fully. Ordinary basic-Bessemer and insufficiently deoxidized open-hearth steels are susceptible to embrittlement. Examination of fractures of welded structures and laboratory tests have shown that there is a connection between this susceptibility and the heat-treatment, degree of deoxidation, and phosphorus content of the steel, and this appears to be independent of grain size. Basic-Bessemer steel can be given a low susceptibility if the contents of non-metallic inclusions, phosphorus, and oxygen are kept low.—J. P.

How to Evaluate Deep Drawing Quality Steel. S. Epstein and J. W. Frame. (Iron Age, 1950, vol. 166, Nov. 9, pp. 88–92). It is suggested that a large bulge test be used to determine the drawability of steel. In this test a 14-in. disc held down at its circumference is burst by oil pressure and the amount of stretch in the upper part of the bulge after bursting is measured. This test has the advantage over a tensile test of being uninfluenced by preferred orientation. The authors also discuss the effects of inclusions and residual elements on drawability.—A. M. F.

Failures in Wire Ropes: Investigation of Metallurgical Features. A. E. McClelland. (Iron and Coal Trades Review, 1951, vol. 162, Feb. 16, pp. 387–394). The author discusses breakages in the various types of colliery ropes investigated by the Safety in Mines Research Testing Branch (Ministry of Fuel and Power) over a period of 12 years, and analyses the predominant causes of failure. He concludes that the greatest hazard to wire ropes in this country is corrosion, often leading to corrosion-fatigue, and suggests that the zinc-coated rope should be adopted as standard for colliery purposes. Means of minimizing other causes of failure are also suggested.—G. F.

Why Machine Parts Fail. Part I—Fracture and Inherent Strength. Part II—Origin and Growth of Cracks. Part III—Modes of Failure. Part IV—Fatigue Fractures. Part V—Bending and Tensile Fractures. Part VI—Torsional Fractures. Part VII—Failures Originating on the Drawing Board. Part VIII—When Not to Blame the Designer. C. Lipson. (Machine Design, 1950, vol. 22, May, pp. 95–100; June, pp. 111–116; July, pp. 141–145; Aug., pp. 157–160; Sept., pp. 147–150; Oct., pp. 97–100; Nov., pp. 158–162; Dec., pp. 151–156). The recognition, classification, and analysis of metal fractures are discussed on the basis of the author's experience.—R. A. R.

Cumulative Damage in Fatigue. K. W. Mitchell. (Metallurgia, 1951, vol. 43, Jan., pp. 25–28). In normal fatigue testing, a particular form of load cycle, with simple or combined stresses, is repeated until the specimen breaks. There are numerous cases where there are occasional applications of stresses very much higher than those which occur a large number of times. Whilst the effects of under-stressing and over-stressing have been investigated, there appears to be no generally accepted rational manner of formulating a simple laboratory test condition which will evaluate the ability of a material to withstand random fluctuations of stress.—J. B. B.

Size of Section and Fatigue Strength in Relation to the Material. H. Wiegand. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Feb. 1, pp. 89–91). Whereas the tensile test on a small specimen gives sufficient information about the static strength of a structure, the analogy does not hold for fatigue strength. After a review of German work on the size effect in fatigue, the author summarizes these results under four headings: Size effect and the method of loading; material; heat-treatment and shaping history; and surface quality. He concludes that the data are insufficient and that much work still remains to be done.—J. G. W.

Factors Influencing the Determination of Fatigue Strength from the Static Yield Point. A. Schaal. (Zeitschrift für Metallkunde, 1950, vol. 41, Oct., pp. 334–339). The fatigue strengths of 18 different steels of high purity were determined under standard conditions on a bending machine, and are listed with their yield points or 0·2% extension limits. These and X-ray methods demonstrate the dependence of fatigue strength on yield point, but there are anomalies. It is shown that the effects of strain and of tensile strength are small, whilst that of grain size is significant. Thus if the mean grain diameter is less than 10^{-4} cm., or the samples have undergone severe plastic distortion, or contain foreign matter or alloying elements, the fatigue strength is greatly reduced. The influence of a surface layer is generally unimportant. Strictly, the results apply only to specimens 7·52 mm. in dia., but if these considerations are allowed for, it is considered possible to calculate fatigue strengths quite accurately from the yield points.—N. MCE.

On the VDI Draft for Standard "Hardness Testing, Holding Fixtures." P. Melchior. (Metall, 1950, vol. 4, Aug., pp. 321–329). The draft, which is reproduced in full, is briefly introduced by the author. It contains drawings and descriptions of 20 different fixtures for holding the parts to be tested. These are so designed as to avoid common testing faults and to expedite testing of a large number of similar articles.

J. G. W.

Microhardness Tester for Metals at Elevated Temperatures. A. Brenner. (Journal of Research of the National Bureau of Standards, 1951, vol. 46, Feb., pp. 126–131). An apparatus has been devised for measuring the hardness of electrodeposited coatings at temperatures up to 900° C. in an inert atmosphere.

Coatings thicker than about 0·07 mm. (0·003 in.) may be tested. The main parts of the apparatus are : (1) The indenting mechanism, consisting of a Vickers diamond mounted on a shaft of fused silica ; (2) a mechanical device for raising and lowering the indenter ; (3) a micrometer device for orientating the specimen under the indenter ; and (4) the heating unit. The force on the indenter is varied either by dead-weight loading or by changing the gas pressure inside the apparatus. Some typical measurements made with the apparatus are given.

A Theoretical Investigation of the Effect of Specimen Size in the Measurement of Hardness. R. Hill. (Philosophical Magazine, 1950, vol. 41, Seventh Series, Aug., pp. 743–753). The theory of plane plastic strain due to Hencky and Geiringer is applied to calculating the minimum dimensions for rectangular specimens to be used in hardness tests. With the aid of strain diagrams, relationships between these dimensions, angle and depth of penetration of the wedge, and load applied are worked out, but an error occurs since the third dimension is not taken into account.—N. MCE.

How Can Hardness Values be Used in Metal Design? J. B. Campbell. (Materials and Methods, 1950, vol. 32, Dec., pp. 43–47). The author describes briefly and in general terms how far hardness values can be relied upon to predict various service characteristics of metals. The Brinell, Rockwell, and Vickers diamond indentation tests are described, and their applications and limitations outlined. The relationships between hardness and strength, wear resistance, machinability and formability are discussed.—P. M. C.

Brittleness in Heat-Treated Alloyed Constructional Steels. J. Chodorowski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 353–356). [In Polish]. A short survey of the literature on this problem is given.—V. G.

Comparison of Mechanical Properties of Products As-Rolled and after Annealing. R. Edelbloude. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 843–855). Results are given of experiments carried out mainly on open-hearth and Bessemer mild steels to determine : (*a*) Mechanical properties after hot rolling at different temperatures and after subsequent annealing ; (*b*) the effect of work-hardening on the transverse properties of the steel ; and (*c*) the effect of cold finishing.—A. G.

The Phenomenon of Wear—A Practical Device for Testing Abrasion. N. G. Neuweiler. (Microtecnic, 1950, vol. 4, Nov.–Dec., pp. 308–314). The instrument described is a sensitive testing instrument for measuring the rate of wear of surface finishes subjected to rubbing abrasion. Its sphere of application includes a wide range of metallic and non-metallic materials and coatings. The device consists of the following main components : Abrasion unit with driving motor, internal timer, power regulator, vacuum pick-up turbine, and step-down transformer. Methods of preparation of rigid and flexible specimens are described, and recommendations are made for testing paint and enamel, plastics, electroplate, paper and cardboard, porcelain enamel, linoleum, wax coatings, and textiles.—E. T. T.

Permanent Magnets. C. Vuilleumier. (Von Roll Mitteilungen, 1950, Dec., pp. 65–96). After a brief statement of the fundamental laws of magnetism, the article recalls the characteristics of hysteresis curves. Operating conditions of magnets in a magnetic circuit, the distribution of the magnetic flux, and the uses of modern magnetic alloys are discussed. The manufacture of permanent magnets at the Klus Works is described.—E. C. S.

A Study of the Magneto-Resistance of Silicon-Iron. R. Parker. (Proceedings of the Physical Society, Section B, 1950, vol. 63, Dec. 1, pp. 996–1004). Iron containing a small percentage of silicon in solid solution has an unusually small magneto-resistance. Longitudinal and transverse curves of $\Delta p/p$ (*i.e.*, the relative change in electrical resistivity on magnetizing a specimen) against field strength were obtained for a number of single and polycrystalline specimens. In large fields the curves show a linear decrease, which is less than 0·02 times that of nickel and cobalt in the corresponding field range. In small fields various unusual features were found. It is concluded that the small magneto-resistance of polycrystalline silicon-iron is due to the small contribution of individual crystallites and not to an 'averaging-out' process.—C. J. B. F.

Magnetic Properties of Ferrites Mixed with Magnesium and Zinc. C. Guillard. (Comptes Rendus, 1951, vol. 232, Mar. 5, pp. 944–946). Compounds of the form $(Fe^{++}{}_x, Mg^{++}{}_x, Zn^{++}{}_{1-x})$ are studied with x varied between 1 and 0. In addition to composition, magnetic moment is governed by the distribution of ferric ions in the tetrahedral and octahedral cavities in the lattice. By extrapolation from the lower values on the magnetic-moment/composition curve a value of $10\mu B$ was obtained for zinc ferrite. Curie points vary inversely with the ferrite content.—A. G.

Residual Isothermal Magnetism of Magnetite in Fine Dispersed Grains. J. Roquet. (Comptes Rendus, 1951, vol. 232, Mar. 5, pp. 946–948). The susceptibility of cylindrical specimens of kaolin with 0·5 or 1·0% by weight of magnetite (mean size 0·1 micron) was measured in a weak field of 30 oersteds. Values of $x_1 = 330 \times 10^{-6}$ (0·5%) and $x_2 = 720 \times 10^{-6}$ (1·0%) were obtained. The ratio of specific magnetisms σ_1 and σ_2 as measured three minutes after the application of a field H for 30 sec. was 2·3, nearly equal to x_1/x_2.—A. G.

Paramagnetic Peculiarities of Solutions of Iron and Cobalt Salts. Y. Ayant. (Comptes Rendus, 1951, vol. 232, Mar. 19, pp. 1203–1204). The anomaly of the moments of Fe^{++} and Co^{++} ions is explained by a partial blockage by the Stark effect produced by ions of opposite sign and the dipoles in water. The theory agrees with experimental values to within 1%.—A. G.

The Zener Effect in Metals. I. Barducci. (Alluminio, 1950, vol. 19, No. 4, pp. 324–333). [In Italian]. The internal dissipation of energy in vibrating solids may be attributed to a number of causes, each of which may become predominant. For example, the loss of energy in a small bar submitted to flexural vibrations is due principally to a thermoelastic effect (Zener effect). Moreover, to this effect may be imputed, at least in part, the loss of energy in metals in the polycrystalline state even when submitted to other forms of vibration. In ferromagnetic metals a substantial part of the loss is due to a magneto-elastic effect, the theory of which Zener has likened to that of the thermoelastic effect. The author refers to the principal conclusions of Zener's theory and shows how, by it, it is possible to foresee in many cases the magnitude of the losses and so explain a number of experimental results.—M. D. J. B.

The Intermittent Progressive Activation in Some Series of Ferromagnetic Alloys. R. Forrer. (Comptes Rendus, 1950, vol. 231, Dec. 18, pp. 1444–1446). The hypothesis of successive intermediate activations towards the $4s$ and $4p$ states is checked by studying the variation of N_θ (number of interactions at the Curie point) with alloy composition. When N_θ is plotted against atomic % of alloying element in iron–nickel and platinum–cobalt alloys extrapolation to pure iron or platinum gives a value of 6 for N_θ in confirmation of theory. Nickel and cobalt are here called intermittent activation agents in γ-iron and platinum which are not ferromagnetic. Non-ferromagnetic metals can also act as agents, *e.g.*, chromium or manganese in platinum, the alloys becoming ferromagnetic at 19% chromium and 18% manganese.—A. G.

The Industrial Applications of Supersonics. H. Bouillon. (Technique et Humanisme, 1949–50, No. 1, pp. 28–33). The description is given of the applications and improvements by supersonic waves of the following : Removal of occluded gases in melts, cooling curves of solidifying metals, dispersion of one metal phase in another, the tin-plating of aluminium wire, and the fatigue of metals under the action of supersonic waves.—J. J.

The Influence of Small Cavities on the Speed of Sound in Metals. F. Gatto. (Alluminio, 1950, vol. 19, No. 1, pp. 19–26). [In Italian]. A method of studying the influence of small cavities on the speed of sound in metals is described. By measuring the variation of the fundamental frequency in specimens with drilled holes, it has been possible to determine the influence of these holes on the speed of sound. It is shown that variations in these speeds are of magnitude comparable with the variations in density of the test samples. Moreover, it is found that this variation in speed of sound depends in no way on the quality of the material employed. A general formula is given which enables the variation in the speed of sound to be determined in a cylindrical sample by means of a hole of known size and position.—M. D. J. B.

Application of Ultrasonics to the Testing of Materials. L. Bergmann. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, Sept. 4, pp. 711–718). This is a review of ultrasonic techniques for testing materials. Following a brief

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historical survey, the two principal methods, echo-sounding and 'direct transmission,' are discussed separately. An outline of the underlying theory is followed by the description of typical applications. In the second method, in order to minimize, transmission losses contact should be made through a fluid. Examples of apparatus are given for the testing of plates, sheets, and wheel rims, etc. Pohlmann's apparatus in which the sound image is converted into an optical one is described in detail and illustrations are given of faulty and sound parts of a lead-coated steel plate. Echo sounding apparatus is described, including its application to the measurement of thickness. Attention is also drawn to future applications for studying the crystalline structure of materials. J. G. W.

Latest Developments in Non-Destructive Testing of Materials. O. Vaupel. (Die Technik, 1950, vol. 5, June, pp. 285–288). The author deals with new apparatus for magnetic powder testing, and with supersonic testing. A list of available supersonic techniques is given and the following are briefly described: Pohlmann's method for visual translation of supersonic waves by means of a suspension of aluminium powder in xylol; and the reflection method used in the Sperry Products Inc. Reflectoscope. In the final section non-destructive techniques for measuring wall and coating thickness are listed.—J. G. W.

The Influence of Graphite Form on the Internal Friction of Cast Irons. R. Cabarat, L. Guillet, and C. Prudhomme. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1951, vol. 48, Jan., pp. 47–49). Cylindrical test pieces were subjected to weak high-frequency longitudinal vibrations created electrostatically. At such high frequencies the main source of internal friction will be non-reversible deformations and the results show that graphite lamellæ act as notch stress concentrators increasing damping.—A. G.

Geiger-Müller Counters and Their Use in Engineering. R. Berthold and A. Trost. (Zeitschrift des Vereines deutscher Ingenieure, 1951, vol. 93, Feb. 1, pp. 73–81). The most notable development of the Geiger-Müller counter in recent years is its adaptation to scientific and technical problems which can be solved by means of electronic counters. This adaptation concerns form and size of the counter, its sensitivity for different types of rays, and its resolution at high ray intensities. The same is also true of the amplifiers associated with it. Such counters are used in conjunction with radioactive substances for non-destructive testing of metal parts, for thickness measurements in inaccessible parts and of hot-rolling products. Other applications are those in which the counter acts as a detector of radioactivity, *e.g.*, in tracer techniques. It is also being used in conjunction with X-rays for the study of metal structure and elastic stresses.—J. G. W.

Coefficients of Thermal Conductivity in Materials Used in the Construction of Heat-Transfer Apparatus. G. delle Canne. (Chimica e l'Industria, 1951, vol. 33, Jan., pp. 11–15). [In Italian]. The factors which influence the total coefficient of thermal conductivity in heat-transfer vessels are briefly examined and the nature of the surfaces through which the heat transfer takes place is studied. The thermal conductivities are given for a large number of steels, non-ferrous alloys, and refractories.—M. D. J. B.

A New Mechanically Registering Dilatometer for the Physicothermal Analysis of Materials, and the Measurement of Their Change in Length with Equipment for Studying Isothermal Quenching. P. Chevenard. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 805–816). After a statement of the problems involved, differential and true dilatation curves, together with the apparatus needed to produce them, are discussed. The scales, distortion, and resolving power of the curves obtained are considered. A description is given of a mechanical method for raising the specimen temperature according to a law given in advance. The dilatometer has been adapted to the study of isothermal quenching and examples of curves for this and other subjects are given.—A. G.

Austenite Formation during Tempering and Its Effects on Mechanical Properties. E. F. Bailey and W. J. Harris, jun. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 997–1000; Journal of Metals, 1950, Aug.). An investigation into the formation of austenite during tempering below the A_1 point, and its effects on the mechanical properties of a low-carbon manganese–nickel steel, is described. It is shown that the amount of austenite formed and its decomposition characteristics depend on time and tempering temperature. Transformation of the austenite during cooling, or during plastic deformation in tensile or impact testing, results in increased tensile strength, decreased ductility, and reduced notch toughness.—G. F.

Progress with Stainless and Heat Resisting Steels. J. Lomas. (Engineering and Boiler House Review, 1950, vol. 65, Oct., pp. 323–324). The oxygen lance method of refining steels makes it possible to use large amounts of scrap, previously regarded as unusable for the arc furnace, and to lower the carbon content to 0·05% without loss of chromium. Low carbon (0·03% C max.) stainless steels may be welded. A stainless steel (12–22% Cr, 10–21% Ni, 0·01–2% Mn, 2–4% Mo, 2–4% Cu, 0·01–0·15% C, and 0·2–1·1% Nb) for high temperature work and a hardenable type stainless steel (22–32% Cr, 1–10% Mn, $\leqslant$ 8% Ni, $\leqslant$ 1·0% Si, and C $\leqslant$ 0·6%) which, on heating to 760° C., attains a hardness of Rockwell C 38 or more have been developed. A new stainless steel containing 0·07% C, 17% Cr, 7% Ni, and 1% Al has a high compressive yield strength, and another steel containing 0·05% C, 16·5% Cr, 4·0% Ni, and 4·0% Cu has a greater corrosion resistance than any of the known hardenable stainless steels. Both these steels may be precipitation-hardened. A chromium–nickel austenitic stainless steel, which work-hardens much more slowly than the standard 18/8 type and which remains non-magnetic after severe cold working, contains on an average 18% Ni, 16% Cr with 0·08% max. C. A new process has been developed for fusion-bonding a corrosion-resisting steel on to a carbon steel backing. E. C. S.

The Principal Properties of So-Called Stainless Steels. A. de Sy. (Mémoires de la Société Royale Belge des Ingenieurs et des Industriels, 1949, Series B, Sept., pp. 137–154). A description is given of the properties of various stainless steels. These are defined as steels containing not less than 12% chromium, which creates a passive surface layer of Cr_2O_3. Other alloying elements used are nickel, copper, molybdenum, titanium, and niobium of which nickel is the most important, providing resistance to attack by reducing acids. Descriptions are given of the following steels: (1) Martensitic chromium steels, (2) ferritic chromium steels, (3) austenitic chromium–nickel steels, and (4) chromium–nickel steels of mixed $\gamma + \delta$ structure. It is pointed out that whereas such steels have, in general, great resistance to corrosion, they can be attacked by (*a*) local corrosion in general, (*b*) intercrystalline corrosion, (*c*) pitting, and (*d*) corrosion producing cracks. It is pointed out that an exact knowledge of the resistance to those forms of attack of all the various steels mentioned is essential to enable the choice of the correct steel for a particular use and to avoid errors in its fabrication. It is emphasized that a high degree of chemical, physical, and mechanical homogeneity is essential to obtain the best results from any particular steel. Many examples are quoted and illustrated.—J. J.

Development of Stainless Steels. W. Tofaute. (Instituto del Hierro y del Acero, 1950, vol. 3, Apr.–June, pp. 90–100). [In Spanish]. Whilst, with engineering steels, a progressive improvement in properties was obtained, which in turn often led to a revision of the original methods of development, in the case of corrosion-resisting steels the early results were obtained with alloys which, today, are still counted as the most stable chemically. The author discusses the reasons for this trend and describes the stainless steels on the basis of Krupp developments.—R. S.

Stainless Steels in the Construction of Rolling Stock. (Aciers Fins et Spéciaux Français, 1950, June, pp. 29–37). Stainless steel (18/8) is used in the construction of rolling stock by the Budd process. The best results are given by stainless steels containing 0·12–0·15% C, 17–19% Cr, 7–8·5% Ni, 0·5% Si, 0·5% Mn, 1–3% Mo (optional), 0·5–2% Ti, 0·04% S, 0·03% P. The tensile strength of a stainless steel carriage is greater than that of an ordinary steel carriage of similar design but weighing 20% more. The use of stainless instead of ordinary steel may result in a reduction of 10% or more in weight.—E. C. S.

French Standards in the Steel Industry. E. Dupuy. (Metallurgia Italiana, 1950, vol. 42, Nov., pp. 393–403). A detailed description is given of the French standards covering the complete range of iron and steel products. The standards are divided into four groups. The first covers generalities, terminology and definitions, and the classification of steels

by their chemical composition; the second covers methods of testing, mechanical, metallurgical and chemical; the third covers shape factors and geometrical dimensions, weights and tolerances; the fourth specifies the qualities and characteristics of steels including ordinary mild and medium steels, special and alloy steels, pig irons and special products. The standards also include specifications for raw materials such as coal, coke, and refractory materials. The results and consequences of standardization are considered as well as the unification of specifications.—M. D. J. B.

Subzero Properties of Metals Surveyed. E. J. Ripling. (Iron Age, 1950, vol. 166, Oct. 19, pp. 76–80; Oct. 26, pp. 53–57). The author presents a critical survey of the properties of metals at subzero temperatures and gives many references. The main conclusions are that steels for use at low temperatures should be thoroughly deoxidized and fine-grained; the carbides should be spheroidal rather than lamellar; tempered martensitic steels behave more favourably at subzero temperatures than do pearlitic steels. The effect of composition is discussed and it is pointed out that only face-centred cubic metals retain their toughness and ductility at low temperatures. The poor performance of martensitic steels near 600° F. has been investigated by the author and it is suggested that this is due to a defective condition which could be overcome by previous working at room temperature; this deficiency has been labelled 'rheotropic embrittlement.' A. M. F.

The Action of Low Temperatures on the Properties of Ordinary and Special Steels. (Aciers Fins et Spéciaux Français, 1950, June, pp. 12–15). Below − 100° C. steels harden and lose their ductility. A drop in temperature below atmospheric temperature rapidly produces a considerable loss in resilience in ordinary steels. In special steels with a nickel content > 1%, this brittleness is almost wholly absent at medium low temperatures. In steels containing unstable austenite a temporary drop in temperature may cause a permanent change in properties. For example, cold treatment increases both the hardness of certain case-hardened and quenched steels by 2 to 10 Rockwell points, and the dimensional stability of gauges.—E. C. S.

Studies on the Strengths of Metals at Low Temperatures. K. Wellinger and W. Seufert. (Zeitschrift für Metallkunde, 1950, vol. 41, Oct., pp. 317–321). An apparatus is described in which the yield of metal specimens under high pressures could be measured, either at room temperature or at that of liquid air. From the flow curves obtained it was shown that metals could be divided into two classes: (1) Soft iron, steel, and magnesium, which have cubic body-centred or hexagonal crystal cells. This helps to explain their brittleness at low temperatures. (2) Aluminium, copper, lead, and austenitic steel, which have cubic face-centred cells, and high tenacities at low temperatures. This classification agrees with previous data on resistance to vibration. With the first class it was demonstrated that distortion at − 183° C. by compression or extension had no lasting effect, hence only the elastic properties were involved; this contrasted with the aluminium class, as the flow curves also showed. All these results, it is claimed, fit in well with theory.—N. McE.

On the Strengths of Metals at Low Temperatures. A. Kochendörfer. (Zeitschrift für Metallkunde, 1950, vol. 41, Oct., pp. 322–325). It is shown that with the aid of existing knowledge a quantitative explanation can be given of the results of Wellinger and Seufert on the thermal variations of yield point and rigidity of metals at low temperatures. The difference between the behaviours of metals with cubic face-centred and with cubic body-centred crystal cells is due to the relatively important part played in the first case by the grains themselves and in the second by the grain boundaries. It is also explained why the properties of metals with cubic face-centred cells are affected by their previous treatment at low temperatures, whereas the metals in the other class do not show this.—N. McE.

'Flakes' in Steel Pieces. A. Portevin and E. Prétet. (Revue de Métallurgie, Mémoires, 1950, vol. 47, Dec., pp. 889–894). The appearance, size, and properties of flakes are described. The steels most prone to this fault being hypereutectoid ones, particularly those containing chromium and tungsten, and special steels containing nickel, chromium, and/or molybdenum. The effects of structure, working, and speed of cooling are considered. Flakes may be avoided by a preliminary 'soaking' to reduce heterogeneity, by the choice of the weight and form of the ingot, by control of forging temperature, and above all by slow cooling after forging.—A. G.

A Direct Cause of 'Flakes.' J. G. Platon. (Société Française de Métallurgie: Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 856–862). Flakes are confined to definite zones of the ingot and are particularly associated with nickel–chromium steels, not auto-quenching. Their characteristics have been investigated by the author over many years by taking test pieces from forgings. Flakes are the residues of internal ruptures caused in the ingot mould although other factors may aid their formation. Basic steels are more prone to them than acid. Hydrogen and nitrogen may be undesirable but are not the primary cause. Flakes in a Ni–Cr–Mo steel are eliminated by compression at a temperature between 800 and 1000° C.—A. G.

Hydrogen Embrittlement of SAE 1020 Steel. J. B. Seabrook, N. J. Grant, and D. Carney. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1317–1321; Journal of Metals, 1950, Nov.). The authors describe an investigation to determine quantitatively the relationship between hydrogen content and degree of embrittlement in SAE 1020 steel containing 0·19% C, 0·40% Mn, 0·012% P, and 0·036% S. Tensile test bars were machined from the hot-rolled steel and cathodically charged with hydrogen, the necessary hydrogen determinations being made by vacuum fusion using a molten tin–iron bath, and true-stress/true-strain tensile tests were made with and without ageing of the bars and at various strain rates. The results show that a certain minimum strain is necessary to cause embrittlement, this strain being greater than the elastic or yield strain for this steel, and as the strain rate increases, less embrittlement is noted. At a hydrogen content of 5 p.p.m., elongation and reduction of area attain minimum values.—G. F.

Hydrogen Elimination by Aging. C. E. Sims. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, p. 1321; Journal of Metals, 1950, Nov.). The author briefly describes an investigation into the elimination of hydrogen from cast steel by ageing, in which three bars originally containing 0·3 relative volume were held at room temperature for 1310 days. The hydrogen content was found to have decreased to 0·096 relative volume, and the ductility had increased sharply. These results confirm predictions made in an earlier paper by the author and his collaborators.—G. F.

Conservation of Columbium. (Metal Progress, 1950, vol. 58, Nov., pp. 691–708, 742–784). Fifty-four letters give the opinions of British and American metallurgists on a proposal of J. F. Tyrrell that titanium-stabilized steels should be substituted for columbium-stabilized steels. The metallurgists consider the respective needs of the aircraft and chemical industries, steel producers, foundrymen, and tube makers. The main points are summarized by a further article by Tyrrell. The chief conclusion is that columbium-bearing alloys can be replaced satisfactorily almost always, and this has long been done in Britain.—E. T. L.

Influence of Various Heat-Treatments and Alloy Additions on the Work-Hardening of Steel. G. Niebch and A. Pomp. (Stahl und Eisen, 1950, vol. 70, Dec. 7, pp. 1166–1173). Seven low-alloy steels of different compositions (increased contents of manganese and/or silicon, with additions of chromium and/or vanadium) and an unalloyed steel, prepared in each of three different conditions (annealed, normalized, and soft annealed) were cold rolled with up to 40% reduction and tested for increase in hardness. The amount of work hardening depended very markedly on the initial heat-treatment. The annealed and soft annealed specimens showed the minimum initial hardness and the smallest increase on reduction, the difference between the steels being small. Differences due to the composition of the steel showed themselves when the samples were normalized. There was no regular relationship between initial hardness and work-hardening. In the normalized state, the initial hardness and degree of work-hardening of the unalloyed and three manganese steels were very similar to those of all the steels in the annealed states, but the four chromium steels showed much higher values of these properties. The results show that: (1) Chromium increases the work-hardenability of steel and that its effect is enhanced by the presence of manganese; (2) manganese and silicon have much less effect; and (3)

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vanadium has no important influence. The influence of alloy additions depends on the initial condition of the steel. [This paper has been translated, *see* Iron and Steel Institute Translation Series No. 418].—J. P.

High-Duty Alloy Cast Irons. C. R. van der Ben. (Alloy Metals Review, 1950, vol. 8, Dec., pp. 2–8). Modern high-duty cast irons, the methods of making alloy additions, and some of their special properties are reviewed. Sixteen micrographs show structures. In particular cases properties of acicular and alloy pearlitic irons are compared. The highest mechanical properties in the as-cast condition are obtained with nodular iron containing nickel plus sufficient molybdenum to produce an acicular structure.—R. A. R.

Production and Properties of Nodular Cast Irons. A. de Sy. (Société Royale Belge des Ingenieurs et des Industriels, Bulletin, 1950, Series A, No. 1, pp. 3–9). A survey is made of the conditions under which nodular cast iron may be produced and of its properties. Examples are given in macro- and micro-photographs of the great promise of these materials.

New Experiences with Nodular Graphite Cast Iron. B. Tyberg. (Gjuteriet, 1949, vol. 39, No. 8, pp. 117–125). [In Swedish]. The author reviews the structures and properties of nodular graphite cast iron as investigated by British research workers. Similar results have been obtained by Americans using magnesium instead of cerium to obtain the nodular structure.—B. S. E.

Brake Drum Materials. F. J. Walls. (Society of Automotive Engineers : Foundry, 1950, vol. 78, July, pp. 68–69, 182–184, 186). No single metal has all the desirable properties of a brake-drum material and it is therefore necessary to compromise. The problems of absorbing and dissipating heat energy caused by vehicle braking and the physical and metallurgical factors involved are examined, with the object of improving brake drum performance.—E. J. D. S.

Wear-Resistant Cast Iron. B. Tyberg. (Gjuteriet, 1949, vol. 39, No. 10, p. 160). [In Swedish]. The hardness and wear resistance of martensitic iron can be improved by nickel and chromium additions, which tend to depress the formation of soft pearlite. Examples of compositions for maximum hardness and tensile strength are given.—B. S. E.

Cast Iron as a Constructional Material. P. O. Björkman. (Gjuteriet, 1949, vol. 39, No. 3, pp. 33–43). [In Swedish]. The metallurgy and metallography of cast iron and the properties and applications of some corrosion-resistant and wear-resistant cast irons are dealt with.—B. S. E.

Engineering Properties of Iron Castings Can be Improved by Heat Treatment. C. E. Herington. (Materials and Methods, 1950, vol. 32, Dec., pp. 50–53). The author describes the compositions, structures, properties, and possible heat-treatments of Meehanite irons. The material has an accurately controlled graphite structure and contains no free ferrite. Tensile strengths above 75,000 lb./sq. in. and Brinell hardness up to 500 can be achieved by oil quenching from 1600° F., while a flame-hardened surface will approach 600 Brinell to a case depth of $\frac{3}{16}$ in. The necessary procedure for these treatments is outlined, together with those for annealing, martempering, and spheroidizing.—P. M. C.

Symposium on the Metallurgy of the Internal Combustion Engine, Part III. Some Metallurgical Aspects of the One-piece Automobile Valve. E. W. Cox. (Australian Institute of Metals : Australasian Engineer, 1950, Nov. 7, pp. 99–107, 109–111). A survey is given of exhaust valve materials from early in the century to 1949, followed by a brief account of the methods of forging the one-piece valve. Mechanical and chemical properties required of a valve under operating conditions are discussed. Three main types of material are in present-day use, (*a*) martensitic, (*b*) transformation hardening, and (*c*) austenitic steels. Their usefulness and reaction to heat-treatment are discussed in some detail, and some microstructures are illustrated. Evidence is given of the simultaneous formation of alpha phase, gamma phase, and carbides in the heat-treatment of B.S.970, En 59 steel. Microstructures illustrate the progressive formation of sigma phase during the heat treatment of XCR steel (Ni, Cr, Mo). There are 12 references.—P. M. C.

METALLOGRAPHY

Austenite Grain Size and Martensite Structure. B. D. Enlund. (Jernkontorets Annaler, 1950, vol. 134, No. 11, pp. 553–555). [In Swedish]. Determination of fracture number in a steel with 0·77% C but with varying martensite structures indicated that the fracture is controlled only by the austenite grain size and is independent of the quenched structures.—B. S. E.

Gamma Ray Metallography. J. Ternisien. (Microtecnic, 1950, vol. 4, Nov.–Dec., pp. 321–325). The method consists of placing a radioactive source at a given distance from one face of the part to be radiographed and a photographic film in a light-proof cassette between intensifying screens against the other face ; the whole is left in position for a suitable exposure time, after which the film is developed. The following variable parameters on which the correct exposure time depends are explained : Distance between the source and the film, thickness of the part, intensity of the source, type of film, type of intensifying screen, and method of film development.—E. T. T.

Method of Measurement and Definition of Surfaces. H. Becker. (Microtecnic, 1950, vol. 4, Sept.–Oct., pp. 276–282 ; Nov.–Dec., pp. 302–307). The microphotometric process according to Heyes and Lueg is based on alternative illumination of the surface in bright field and in dark ground. A photoelectric cell is used for the measurement of the luminous flux. There are several other optical methods for measuring and defining a surface, but none of them furnishes well-defined numerical values such as are obtained by the light cross-section method. The second group of surface inspection devices consists of tracer instruments. The vertical movement of the needle when exploring surfaces is so small that it must be amplified by suitable mechanical, optical, or electrical means. In this connection three points are dealt with, namely : Tracer point radius, tracer point pressure, and recording of the surface explored. Practical experiments have shown that a tracer point radius of 10μ is quite satisfactory. The tracer point pressure is the higher the smaller its radius. The profile curve produced by the tracer must be recorded in co-ordinates in order to make evaluation possible. The author describes the operation of the following recording instruments : Woxen surface indicator, Talysurf instrument, profilometer, surface analyser, Perthograph, and the Leitz surface analyser. E. T. T.

Local Distribution of Inclusions in Steel and Its Effect on the Reliance to be Placed on Their Counts. A. Palazzi. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, Dec., pp. 907–929). Results of experiments relating to the total number of inclusions in steels are given. Poisson's Law for small groups governs the distribution of collections of inclusions across a large number of fields and also applies when the inclusions are subdivided into groups, *e.g.*, sulphur, silicate, and oxide. A law is obtained giving the number of fields to be examined to give a mean inclusion count with a predictable error. An inclusion index obtained under standard conditions showed an inverse correlation with the mechanical properties of the steel.—A. G.

Study of the Structure of Surfaces. G. Blet. (Publications Scientifiques et Techniques du Ministère de l'Air, 1950, No. 241). This study is divided into two parts, the first being on the determination of the orientation of elementary facets in a hyperfine surface, and the second part on rough surfaces. Theoretical and experimental details are given and compared of photographic and photometric methods of studying surfaces.—J. J.

The Electrolytic Polishing of Metallographic Specimens. (Hutnik, 1950, vol. 17, Sept.–Oct. : Biuletyn Informacyjny Glownego Instytutu Metalurgii i Odlewnictwa, No. 7–8, pp. 25–27). [In Polish]. The electrolytic polishing of metallographic specimens is described.—V. G.

Correlation between JKM-Fracture Number and Grain Size for Hardened Steels. B. D. Enlund. (Jernkontorets Annaler, 1950, vol. 134, No. 11, pp. 545–552). [In Swedish]. A linear correlation was found between the Jernkontoret fracture number and grain size in high-carbon hardened steels. The grain size was determined after etching in alkaline sodium picrate solution. This method revealed the slightly decarburized grain boundaries better than the method suggested by Bain-Vilella.—B. S. E.

Nucleation Processes in Solid Solutions. P. Laurent. (Société Française de Métallurgie : Revue de Métallurgie, Mémoires, 1950, vol. 47, Nov., pp. 835–842). After considering the various theories of nucleation in pure metals and solid solutions the author advances a new theory. This postulates two different modes of germination, namely, by fluctuation and by nucleation, each with an intermediate state which, in the

case of nucleation, corresponds to Guinier zones. The theory only involves thermodynamic changes and instantaneous fluctuations.—A. G.

Metallurgical and Metallographical Aspects of Grey Cast Iron. B. Tyberg. (Gjuteriet, 1949, vol. 39, No. 1, pp. 1–11). [In Swedish]. This paper is a summary of a literature survey, dealing with crystallization and transformation of normal grey cast iron, the mechanism of graphite formation and its theories, and the influence of dissolved gases. Mention is made of recent inoculation methods.—B. S. E.

Structure Control and Structure Diagrams for the System Iron–Carbon–Silicon. S. Toresson. (Gjuteriet, 1949, vol. 39, No. 5, pp. 69–78). [In Swedish]. The influence of carbon and silicon on the structure and properties of grey iron castings has been considered important by Maurer and others. The developments at the Götaverken foundries have largely been done with this in mind. Osann, however, assumed the silicon influence to be predominant. Analytical data and production control methods concerning the Götaverken foundries are presented.—B. S. E.

On the Crystallographic Orientations of Crystal Surfaces in Metallographic Specimens. H. Kostron. (Zeitschrift für Metallkunde, 1950, vol. 41, Oct., pp. 370–377). A method of preparing specimens, so that the orientations of microscopic crystals can be found, is explained. Etch figures, generally triangular, can give the necessary data, but the triangles are liable to be distorted, and it is better to use the slip lines which are formed when a thin sheet of the metal is bent in one or more directions. Aluminium is taken as an example of a cubic metal, and the procedure for calculating the angles of the etched figure and the slip lines is fully described. By means of the tables and diagrams presented one can calculate the lie of the crystal axes in any example, given any three of the angles of the etched figure or the slip lines. Several examples are worked out.—N. McE.

Influence of Alloy Elements upon the Decomposition of Martensite during the Tempering of Steel. S. Z. Bokshtein. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 73, No. 3, pp. 491–494). Investigations were made of the decomposition of martensite in 0·4% carbon steels containing different combinations of nickel, manganese, chromium, molybdenum, vanadium, and silicon, on tempering at temperatures in the 200–650° C. range for periods of from 1 min. to 25 hr. Among the conclusions were: (1) Precipitation of carbon from the α solution in steel alloyed with up to 6% Ni and up to 2·5% Mn is almost complete within the 400–500° C. range. (2) Under the same tempering conditions (below 500° C.) the carbon in the α solution of chromium, molybdenum, or vanadium steel is higher than it is for straight carbon, nickel, or manganese steel. (3) Silicon does not arrest the precipitation of carbon while tempering at 400 to 500° C. (4) Vanadium has the strongest effect in slowing down the decomposition of martensite, molybdenum comes next.

Kinetics of Polymorphic Transformation of Alloyed Iron. L. I. Kogan and R. I. Entin. Doklady Akademii Nauk S.S.S.R., 1950, vol. 73, No. 6, pp. 1173–1176). A magnetometer with photographic recording was used to study the kinetics of the $\gamma \rightarrow \alpha$ transformation of nine iron alloys, the carbon contents being 0·06% or lower and the alloying elements chromium and nickel; chromium, nickel, and molybdenum; and chromium and cobalt. The results include the following: (1) Adding 2·5% Ni to the 8·5% Cr alloy lowers the martensite point 15° C. (2) Increasing the chromium from 5·5 to 8·5% with nickel constant lowers the martensite point 60° C. (3) Adding 3% Co to the 7·5% Cr alloy raises the martensite point to 530° C. while a further increase to 5% Co reduces it to 475° C.

Electron Microscopic Investigation of the Austenite Decomposition in the Pearlite–Troostite Range. V. D. Sadovskii, R. M. Leriman, and A. M. Polyakova. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 71, No. 2, pp. 299–301). An electron-microscope study has been made of the structures obtained on the isothermal transformation at 625°, 575°, and 550° C. of the austenite in an alloy steel (C 0·41%, Cr 1·38%, Ni 3·34%). Lamellar pearlite–troostite is formed at both above and below the temperature of the maximum rate of decomposition in the upper range; the length and thickness of the plates decrease with diminishing decomposition temperature.

Diffusion in the Solid State. H. Buckle. (Recherche Aéronautique, 1949, No. 12, pp. 45–54). An appreciation is made on theoretical and experimental grounds of the diffusion phenomena which are of such great importance in metallurgical processes. This is preceded by an historical survey of the general theories underlying the problems discussed. Detailed descriptions are given of the classical theories of single-phase diffusion and experimental methods used. A section is devoted to heterogeneous diffusion, and unpublished equations are given for these little-known processes. Finally a description is given of the developments of the various hypotheses concerning the mechanism of solid diffusion.—J. J.

Silicon Distribution between Austenite and Liquid Metal in Freezing Hypo-Eutectic Cast Iron. A. Hultgren and O. Karlsson. (Jernkontorets Annaler, 1950, vol. 134, No. 11, pp. 556–558). [In Swedish]. This investigation confirms the distribution diagram for the system iron–carbon–silicon which was worked out by Jass in 1935. The silicon content of the mother liquor of a hypo-eutectic cast iron decreases, whereas the phosphorus content increases during solidification.

B. S. E.

Rule for Temperature Dependence of Solubility of Metals in Iron. I. I. Kornilov. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 72, No. 6, pp. 1067–1070). The author attempts to establish laws relating the atomic diameters to changes in the solubility of elements in iron as a function of temperature. It is shown that the solubility in iron of titanium, zirconium, niobium, tantalum, molybdenum, and tungsten increases greatly at high temperatures, whilst the solubility of aluminium increases by only 2% between room temperature and 1232° C. Reasons for this are given.

The Importance of Metal Physics in the Theory of the Structure of Metals. M. Nacken and E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 3, June, pp. 125–131). The modern electron theory of metals and the deductions therefrom about metal and alloy structures are briefly reviewed.—J. P.

Measurement of Relative Interface Energies in Twin Related Crystals. C. G. Dunn, F. W. Daniels, and M. J. Bolton. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 368–377; Journal of Metals, 1950, Feb.). An investigation into the nature of the boundaries in twin related grains of silicon iron is described, silicon ferrite specimens containing such grains being prepared using the phenomenon of annealing twin formation. The determination of the relative interface energy of the $\{112\}$ twin is described, and the effect of boundary orientation on boundary energy is briefly discussed. The mathematical and experimental techniques employed are discussed in detail.

G. F.

Heat-Treatment of Twinned Iron Crystals. R. I. Garber, I. A. Gindin, M. G. Konstantinowskii, and V. I. Startsev. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 74, No. 2, pp. 343–344). [In Russian]. The investigation of the influence of heat-treatment on disappearance of twinned crystals of iron (caused by non-uniform deformation) is described.—V. G.

The Structure of Spheroidal Graphite. M. Nacken and E. Piwowarsky. (Neue Giesserei, Technisch-Wissenschaftliche Beihefte, 1950, No. 2, Feb., pp. 75–76). X-ray examination of natural, kish, pig-iron, spheroidal, and artificial graphites has shown them all to be of essentially the same crystal structure. The grain size of spheroidal graphite isolated from nodular iron is of the same order as that of graphite from pig iron though slightly smaller. Although the nodules are very prone to fracture into small particles on application of tangential stresses, it was impossible to make an indentation with the diamond of a microhardness tester applied normally to the surface.—J. P.

Kinetics of the Eutectoid Transformation in Alloys of Iron and Nitrogen. B. N. Bose and M. F. Hawkes. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 307–316; Journal of Metals, 1950, Feb.). A report is given of metallographic, X-ray diffraction, and microhardness studies of an iron–nitrogen alloy containing 2·35% nitrogen, the eutectoid composition; this alloy is analogous to the eutectoid iron–carbon alloy with respect to transformations to pearlitic and martensitic structures. At all temperatures, isothermal transformation is slower in the nitrogen alloy than in the carbon alloy, and nitrogen austenite is far more stable than carbon austenite with respect to transformation to martensite.—G. F.

Transformation of Austenite in a Manganese–Molybdenum Steel Deposited as Weld Metal. O. O. Miller, F. C. Kristufek, and R. H. Aborn. (Welding Journal, 1950, vol. 29, Sept.,

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pp. 450s–458s). The isothermal transformation diagram of a manganese–molybdenum steel deposited as weld metal has been determined. A transformation diagram (for cooling) has been derived and correlated with cooling rates in typical weld deposits and in heat-treated steel plate. Data are given for hardness, microstructure of an end-quenched hardenability bar, and transition temperatures.—U. E.

Transformation of Deformed Austenite into Martensite. G. V. Kurdyumov, O. P. Maksimova, and T. V. Tagunova. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 2, pp. 307–310). [In Russian]. The influence of deformation on austenite, kinetics of its transformation into martensite during cooling (to 100° C. below room temperature) and during isothermal low-temperature treatment, and its dependence on this temperature was investigated.—V. G.

The Influence of Additions of Molybdenum on the Mechanism of Eutectoidal Transformation of Austenite. M. E. Blanter. (Doklady Akademii Nauk, U.S.S.R., 1950, vol. 74, No. 4, pp. 791–793). [In Russian]. It was experimentally shown that the eutectoidal transformation of austenite in molybdenum steel takes place in two stages : (1) Diffusion of carbon, and (2) redistribution of alloying elements between ferrite and cementite causing, in some cases, carbide transformation. V. G.

Recrystallization of Austenite Caused by Internal Deformation. K. A. Malyshev. (Doklady Akademii Nauk U.S.S.R., 1951, vol. 76, No. 1, pp. 61–64). [In Russian]. Chromium–manganese steel was quenched to give a coarse grain structure, again reheated at 100° C./sec. and quenched in water. The α–γ transformation and recrystallization of austenite was followed by observation of fracture and oscillograms of heating. The coarse structure is only destroyed by reheating to 975° C., recrystallization being attributed to internal deformation caused by the volume change accompanying the α–γ transformation.—V. G.

Possible Mechanism of Decomposition of Martensite. Yu. A. Bagaryatskii. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 6, pp. 1161–1164). [In Russian]. On the basis of cited literature, the rearrangement of the atomic lattice during the decomposition of martensite is postulated—V. G.

An Automatic Recorder for Heat Content Curves and for Thermal Analysis with Slow Heating Rates. W. Jellinghaus. Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 65–71). The Sykes apparatus for measuring specific heats has been developed into a recorder for thermal analysis at low heating rates. The sample is placed inside a metal jacket heated at the predetermined rate. A subsidiary heater automaticaly keeps the sample at the same temperature as the jacket and the electricity required for this purpose is measured as a function of temperature. A combination of an electricity meter and a galvanometer attached to the temperature-measuring thermocouple causes a beam of light to trace the heat-content/temperature curve on a photographic plate. The recorder is suitable for use with heating rates of the order of 1° C./min. Some typical curves are shown. The decomposition, during tempering, of residual austenite in excess of 5% is clearly shown.—J. P.

Low Temperature Treatment of Steel and Alloys. A. Towpik. (Przeglad Techniczny, 1951, Jan., pp. 19–23). [In Polish]. The importance of low-temperature (below 0° C.) treatment of steel and alloys is discussed. A short survey of research work on the influence of this treatment on the austenite–martensite transformation is given.—V. G.

A Study of the Iron–Chromium–Nickel Ternary System. J. W. Pugh and J. D. Nisbet. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 268–276 ; Journal of Metals, 1950, Feb.). The constitutional diagram of the iron–chromium–nickel system has been studied by means of hardness, elongation, tensile strength, and dilatation methods, and by microstructure analysis, using 55 high-purity alloys. The data collected verify many of the results of earlier investigations, and the ternary diagrams presented are felt to be as nearly accurate as is possible at present.—G. F.

The Iron–Nitrogen System. V. G. Paranjpe, M. Cohen, M. B. Bever, and C. F. Floe. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 261–267 ; Journal of Metals, 1950, Feb.). The authors describe a study of the phase boundaries of the iron–nitrogen system, using X-ray diffraction measurements and a controlled nitrogenizing method which depends on the relation between the nitrogenizing power of an ammonia–hydrogen gas mixture and the nitrogen concentration of the iron–nitrogen alloy produced. The phase diagram for the system in the temperature range 450–700° C. is given, based on the measurements, and the composition limits and crystal structure of the phases are discussed.—G. F.

An Example of Error Caused by Ignorance of the Principles of Thermodynamics. L. C. Correa da Silva. (Mineração e Metalurgia, 1950, vol. 15, Nov.–Dec., A.B.M. Noticiario, vol. 4, Nov.–Dec., p. 179). [In Portuguese]. In Metals Progress, 1937, vol. 32, p. 342, an equilibrium diagram was published for the iron–carbon system which has been widely used. It is known that the lines limiting the phase stabilities are the geometric locations of the points of contact of the tangents to the surfaces of free energy of these phases, each tangent being drawn at constant temperature. Such geometric construction originates from the necessity of having in the system a minimum free energy. The correct position of the eutectic and eutectoid points are shown. In the 1949 edition of Metals Handbook, the iron–carbon diagram is published correctly.—R. S.

Thermodynamics and Structure of Iron–Carbon Alloys. E. Scheil. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 37–52). An attempt has been made to develop a picture of the structure of iron–carbon alloys, particularly of melts and γ-solid solutions, which can take the place of the carbide hypothesis, according to which carbon is present as cementite. The calculations employed led to the following conclusions : The carbon atoms occupy interstices between iron atoms and the occupation of adjacent interstices is improbable on account of the increased electron density in the vicinity of the carbon atoms. Three types of structure are to be distinguished : (1) Fe_4C sites, the usual interstitial positions ; all adjacent interstitial sites are unoccupied. (2) Fe_4C_3 sites, of infrequent occurrence ; two adjacent interstices are occupied ; and (3) Substitution, very rarely encountered ; of the six normal iron neighbours, one is missing. The following equilibrium curves of the iron–carbon phase diagram have been calculated : BC, DE, C′D′, ES, and E′S′.—J. P.

Metallography of Sintered Carbides. E. Bryjak. (Hutnik, 1951, vol. 18, Jan., pp. 14–24). [In Polish]. Methods of investigation of sintered carbides are described. The systems tungsten-carbide/titanium-carbide, and tungsten-carbide/titanium-carbide/cobalt, and their influence on the structure of sintered carbides are discussed. The tungsten–carbon system is outlined.—V. G.

The Iron–Phosphorus–Cobalt Equilibrium Diagram. J. Berak. (Hutnik, 1951, vol. 18, Jan., pp. 6–13). [In Polish]. The results of investigations of the iron–phosphorus–cobalt system within the limits Fe–Fe_2P–Co_2P–Co, by thermal, microscopical, and X-ray methods are described.—V. G.

Structure of the Sigma-Phase in the Iron–Chromium and Cobalt–Chromium Systems. G. J. Dickens, Audrey M. B. Douglas, and W. H. Taylor. (Nature, 1951, vol. 167, Feb. 3. p. 192). A similarity is noted between the structure of uranium and the sigma phase, which is based on a tetragonal unit cell of 30 atoms. The lattice constants for the sigma phase in iron–chromium alloys are $a = 8{\cdot}79$Å. and $c = 4{\cdot}559$Å. A. G.

Metallography of Carbon in Silicon–Iron Alloys Containing 4% Silicon. E. D. Harry. (Journal of The Iron and Steel Institute, 1951, vol. 167, Mar., pp. 241–246). An account is given of the mode of occurrence of carbon in 4·0% silicon–iron alloys used for the manufacture of transformer sheets. The account starts with the sheet bar, which may contain 0·050–0·10% of carbon, and ends with the finished sheet, which may have been annealed at temperatures ranging from 750–1150° C., and in which the carbon content may vary from below the limit of solid solubility to 0·030%. Mention is made of an effect involving carbon segregation, which has been observed in this material. Pick-up of carbon from the furnace atmosphere during annealing is also described. The constitution of the carbide phase in these silicon-irons is discussed, and it is shown that this phase is duplex in structure, consisting of the ordinary iron–carbide, Fe_3C, and what is believed to be an iron–silicon–carbon compound, the two carbides appearing to form a eutectoid.

The Formation of Sigma and Its Influence on the Behaviour of Stabilized 18 per Cent Chromium 8 per Cent Nickel Steels in Concentrated Nitric Acid. R. S. Stewart and S. F. Urban.

(A.S.T.M. Symposium on the Nature, Occurrence, and Effects of Sigma Phase, June, 1950. Special Technical Publication No. 110, pp. 128–145). **Aluminium Decreases Corrosion Resistance of Austenitic Stainless.** R. S. Stewart and S. F. Urban. (Iron Age, 1950, vol. 166, Aug. 17, pp. 91–95). Austenitic stainless steels (18/8) are sensitive to intergranular corrosion if they are heated in the range 800° to 1600° F. as for instance during welding. Titanium and columbium are frequently added to combat this corrosion but an equally effective method is by decreasing the aluminium which is present in ferrotitanium and as an excess from deoxidation. The corrosion is believed to be due to attack of the sigma phase, a precipitate within the delta ferrite phase, and aluminium is a very potent sigma-forming element.—A. M. F.

CORROSION

The Fight against Corrosion and Its Economic Significance. M. Smialowski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 308–309). [In Polish]. The losses caused by corrosion and efforts to determine their magnitude are briefly discussed.—V. G.

Studies on Galvanic Couples. I—Measurement of Electromotive Force and Internal Resistance of Cells during Current Flow. II—Some Potential-Current Relations in Galvanic Corrosion. III—Polarization and Cathodic Protection. H. D. Holler. (Journal of the Electrochemical Society, 1950, vol. 97, Sept., pp. 271–282; Dec., pp. 453–461). Under laboratory conditions of restricted aeration in wet clay, polarization of an iron–hydrogen couple by an applied current may be used to evaluate the internal, *i.e.*, local anode to cathode, current and, therefore, the applied potential and current required to give cathodic protection of iron. The importance of phase-boundary resistances in polarization measurements is demonstrated and methods of interpreting polarization curves and their relation to cathodic protection are described. The application of these principles to cathodic protection when the ratio of cathodic to anodic area is very large and the full importance of the principle of current partition to current distribution should be studied for long distances underground. The criterion of cathodic protection based on applied potential may be useful, particularly where the open-circuit anode potential may vary with conditions and with time. Application of the required constant potential, the applied current adapting itself to that necessary to maintain the constant potential, should result in economy of power. An explanation of hydrogen overvoltage on the basis of polarization of galvanic couples in the phase boundary is suggested. A practical criterion for determining the current or potential required for cathodic protection, in poorly aerated conditions underground, may require detection of the usual hydrogen overvoltage relationship.—J. P.

Studies of Time-Potential Changes on an Electrode Surface during Current Interruption. I. Zinc–Steel Couple in Synthetic Sea Water. S. Schuldiner and R. E. White. (Journal of the Electrochemical Society, 1950, vol. 97, Dec., pp. 433–447). A direct current interrupter method has been developed for oscilloscopic studies of time-potential changes at an electrode surface during short interruption periods. The apparatus is described. A variable length square pulse with a very short rise time and with a duty factor of approximately 1% was used to interrupt the current flow in the cell. Measurements were made during interruption periods of from 1 to 120 microsec. The technique permitted correction for the resistance error in closed circuit potential measurements. Polarization decay and build-up could be followed as the current was switched off and on, and the potential changes and electrical double layer capacity effects occurring at an electrode surface during interruption could be measured. These phenomena are discussed in terms of an equivalent electrical circuit. An initial study of polarization phenomena on the zinc-anode/steel-cathode system in a synthetic sea water was carried out using the interrupter method; the complexity of the behaviour was such that more elementary systems are to be studied to elucidate some of the observations.—J. P.

Effect of Magnetic Transformation at the Curie Temperatures on Oxidation Rates of Chromium–Iron Alloys. H. H. Uhlig and A. de S. Brasunas. (Journal of the Electrochemical Society, 1950, vol. 97, Dec., pp. 448–452). Oxidation rates of chromium–iron alloys (9·2 to 24% Cr) have been carried out in oxygen at temperatures above and below the respective Curie temperatures. Plots of the logarithms of the oxidation rates against the reciprocal of the absolute temperature show discontinuities at the Curie temperatures. In general, activation energies calculated from the oxidation rates are higher above the Curie temperature than below. This lends support to the view that the rate of formation of thin films is controlled by reaction phenomena at the metal–oxide interface. It has been shown earlier that the rate-controlling step may involve electron transfer from the metal; a higher work function for the metal above than below the Curie temperature may be associated with the observed trend of activation energies. Since the Curie temperature is an electronic transition, the data also support the view that electronic changes in the chromium–iron alloys can affect the initial reaction rates.

Existence of a Nucleation Process in the Controlled Oxidation of Iron at High Temperatures. J. Bardolle and J. Bénard. (Comptes Rendus, 1951, vol. 232, Jan. 15, pp. 231–232). Pure Armco iron after oxidation with oxygen, at low pressures or diluted with nitrogen, shows geometrically shaped nuclei of oxidation, each shape having the same orientation within a given crystal. This demonstrates a relation between the orientation of the oxide film and that of the underlying metal.—A. G.

The Prevention of Corrosion in Flue Gas CO_2 Instruments. H. C. Bones. (Instrument Practice, 1950, vol. 5, Nov., pp. 17–21). The corrosion of flue-gas CO_2 recording instruments is due to the production of sulphur during combustion of the fuel. The formation of SO_2 and SO_3, which are dissolved in water from the fuel, produces highly corrosive acids. Two methods of SO_2 removal are described, the more practical being the absorption by sodium bicarbonate. Operating details are given together with a diagrammatic arrangement of such an absorber, incorporated in an Electrofio recorder. Leakages and methods of detection are discussed; emphasis is laid on the need for careful selection of the sampling points.—H. D. W.

Sodium Nitrite as an Inhibitor against the Attack of Sea-Water on Steel. III. Inhibitor in Sea-Water/Distilled-Water Mixtures. T. P. Hoar. (Journal of the Society of Chemical Industry, 1950, vol. 69, Dec., pp. 356–362). The corrosion of mild steel by sea-water/distilled-water mixtures at 25° or 60° C. can be completely inhibited by the presence of a percentage (wt./vol.) of $NaNO_2$ > one-fifth of the sea-water percentage (vol./vol.). Similarly sodium nitrite additions inhibit the corrosion of white metal by such waters, and decrease the corrosion of copper (especially at 60° C.); they have no appreciable influence on the corrosion of brass at 25° C. Corrosion-potential measurements at 25° C. indicate that nitrite is an anodic inhibitor. These and other results suggest that its main action is the oxidation of ferrous compounds to ferric, stannous to stannic, and cuprous to cupric, with a concomitant rise in *p*H, so that the sparingly soluble higher oxides or hydrous oxides are readily precipitated at anodic places and stifle corrosion.—E. C. S.

Electrochemical Behaviour of Paint Films in Sea-Water: A Suggested Mechanism. J. T. Crennell. (Journal of the Society of Chemical Industry, 1950, vol. 69, Dec., pp. 371–373). The cathodic character of painted or otherwise screened steel in sea water may be explained by the retention behind the paint film of the products of reaction of local corrosion couples. Local anodes behind the film will be suppressed by accumulation of ferrous ions. Alkalinity produced at local cathodes renders the steel passive and so encourages passage of further current in the same direction. Experiments are described, showing that an iron electrode transferred from neutral to alkaline salt solution becomes temporarily anodic, then quickly becomes cathodic as passivity develops.—E. C. S.

Use of Magnesium Alloy Anodes in Ship Protection. K. N. Barnard. (Canadian Journal of Research, 1950, vol. 28, Nov., pp. 417–437). The paper describes the results of a 14-month test of magnesium alloy anodes in sea water. The current from the anodes was used to protect cathodically an inactive Algerine class minesweeper. The results obtained show that it is practicable to use magnesium alloy anodes in ship protection and that only a relatively small current is required to prevent the corrosion of underwater hulls of inactive ships. A convenient criterion to determine the amount of current required is given.—D. H.

The Influence of Internal Stresses on Corrosion. E. Franke. (Werkstoffe und Korrosion, 1950, vol. 1, Oct., pp. 404–412). This is a comprehensive review of the literature with 91 references.—O. H. G.

XUM

The Problem of the Conservation of Structures. C. F. Hickethier. (Ingenieria e Industria, 1950, vol. 18, Sept., pp. 66–70). [In Spanish]. The work of the National Association of Corrosion Engineers in the U.S.A. is outlined. A plea is made for less indifference to the havoc wrought by corrosion in metal structures and for the development of studies of material properties. Indications of the work done in foreign countries are given.—R. S.

Corrosion Resistant Materials and Coatings in Trail Chemical Operations. E. A. G. Colls. (Mining Engineering, 1950, vol. 187, Apr., pp. 491–494). An account is given of special materials used for corrosion prevention in various sections of the chemical and fertilizer works of the Consolidated Mining and Smelting Company of Canada, Ltd., at Trail, British Columbia. Anti-corrosion measures are described in the SO_2 and acid recovery plants, hydrogen and ammonia plants, phosphate, sulphate, and nitrate plants. Molybdenum-bearing and columbium-stabilized steels are used extensively. E. C.

Corrosion of Metals in the Light of Modern Physical Chemistry. M. Smialowski. (Hutnik, 1951, vol. 18, Mar., pp. 89–95). [In Polish]. Modern views on corrosion processes of metals are briefly outlined.—V. G.

Concerning the Electrochemical Character of the Corrosion of Metals in Dilute Dielectrics. L. G. Gidin. (Doklady Akademii Nauk U.S.S.R., 1950, vol. 73, No. 3, pp. 515–518). [In Russian]. Based on experimental evidence, the author expresses the view that metal corrosion in dilute dielectrics is at least partly an electrochemical process.—V. G.

Corrosion-Resistant Materials. L. W. Johnson and E. J. Bradbury. (Transactions of the Institute of Marine Engineers, 1951, vol. 63, Apr., pp. 59–80). The paper is in three sections dealing with: (1) The theoretical aspects of corrosion; (2) corrosive media normally encountered in marine engineering; and (3) general corrosion-resisting properties of metals and alloys commonly used to resist the corrosive media encountered. The media discussed under (2) are fuels and the products of combustion, boiler water and steam, sea water, and the atmosphere. Many non-ferrous and ferrous alloys are considered. The coefficients of expansion and thermal conductivities of many corrosion- and heat-resisting steels are given in addition to the usual mechanical properties. R. A. R.

The Change in Flexure of Cast Iron in the Long-Time Corrosion Test. F. Roll. (Neue Giesserei, 1950, vol. 37, Aug. 24, pp. 337–339). Cast-iron specimens of three different qualities were subjected to a bend test for up to 10,000 hr., whilst submerged in sea water; control tests were performed in air, and in addition, specimens made of St70.11 steel were tested. The three cast irons behaved differently; the skin had a protective value, the deflection increased in both air and sea water under constant bending load, the increase lasting for different periods and differing in magnitude, depending on the load and the quality of the cast iron. J. G. W.

Tensile Failure of Carbon and Stainless Steel Wires in the Presence of Water and Hydrogen Sulphide. J. E. Truman. (Metallurgia, 1951, vol. 43, Jan., pp. 8–10). Premature failure of both ordinary and corrosion-resisting steels, in conditions of service involving the presence of hydrogen sulphide, have been investigated. The combination of tap water and hydrogen sulphide at room temperature can produce a very considerable reduction in life of steel specimens stressed to 40% of their maximum stress, although a Cr–Ni–Mo stainless steel showed no visible attack up to 10,800 hr.—J. B. B.

Kinetics of Solid Phase Reactions in Oxide Films on Iron—The Reversible Transformation at or near 570° C. E. A. Gulbransen and R. Ruka. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1950, vol. 188, pp. 1500–1508; Journal of Metals, 1950, Dec.). A description is given of a study of the reversible transformation $Fe_3O_4 + Fe \rightleftharpoons 4FeO$ in oxide films on iron at temperatures at or near 570° C. by electron-diffraction methods. It is shown that the forward and reverse reactions may occur below 570° C. for thin films, and that the forward reaction may occur at temperatures as low as 400° C. At temperatures of 570–630° C., the forward reaction is rapid for thin films but slow for thick films, the mechanism being governed by the diffusion of iron ions through the FeO already formed to reduce the Fe_3O_4. The reverse transformation is a slow reaction for both thin and thick films, and a process of nucleation and growth of Fe and Fe_3O_4 crystals in the oxide lattice is suggested as a possible mechanism for the reaction. The free energy required to precipitate the small iron or Fe_3O_4 nuclei is obtained by a large degree of undercooling. G. F.

The Influence of Thermal Treatment of Mild Steel on the Rate of Intercrystalline Stress Corrosion in Ammonium Nitrate Solution. M. Smialowski, E. Gasior, and C. Bieniosek. (Prace Badawcze Glownego Instytutu Metalurgii, 1951, No. 1, pp. 17–22). [In Polish].

Molybdate and Tungstate as Corrosion Inhibitors and the Mechanism of Inhibition. W. D. Robertson. (Journal of the Electrochemical Society, 1951, vol. 98, Mar., pp. 94–100). Experiments have shown that molybdate and tungstate ions are efficient corrosion inhibitors for iron, comparable in this respect with chromate and nitrite. The concentrations required for complete inhibition are small and dependent on the corrosion conditions. If the concentration is insufficient, corrosion is accelerated, apparently by the formation of local active-passive cells. The mechanism of inhibition does not appear to depend on the co-precipitation of insoluble reduction products of the inhibitor because neither molybdate nor tungstate oxidizes ferrous iron. Inhibition is associated with the presence, at the surface, of the inhibitor itself, and any reaction which reduces its activity decreases its inhibition efficiency. In view of the non-oxidizing character of the two ions, it is suggested that they may find application in systems where chromate and nitrite are excluded as oxidizing agents. J. P.

The Role of Sodium Silicate in Inhibiting Corrosion by Film Formation on Water Piping. L. Lehrman and H. L. Shuldener. (Journal of the American Water Works Association, 1951, vol. 43, Mar., pp. 175–188). Solutions of different sodium silicates in very low concentration (1200–1400 p.p.m. SiO_2) are shown to achieve an equilibrium between ionic and colloidal silica, the rate being slower as the concentration increases. Silica is not removed from these solutions by metals until the solid corrosion products of the metals form. The siliceous film which forms on the corroding metals and inhibits the corrosion process is identified by chemical analysis, microscopic examination, and X-ray diffraction pattern as being predominantly amorphous silica. The mechanism of removal of silica from very dilute solutions of sodium silicate by zinc hydroxide is shown to be adsorption. A description has been given of the film formed by the adsorption compound in galvanized iron and brass piping during actual service. R. A. R.

ANALYSIS

The Use of Schematic Flow Diagrams in the Steelworks Laboratory. H. U. von Vogel. (Archiv für das Eisenhüttenwesen, 1951, vol. 22, Jan.–Feb., pp. 31–36). The use of formalized flow diagrams, using simple symbols, to depict the methods and procedures of iron and steel analysis is recommended. It is claimed that these diagrams are more easily followed and understood than written instructions. Nine typical procedures are illustrated.—J. P.

Separation Methods in Metallurgical Analysis. T. S. West. (Metallurgia, 1951, vol. 43, Jan., pp. 41–45). Recent developments in separation methods are outlined under the following headings: Extraction methods for iron, antimony, uranium, gold, calcium from the alkaline earths, lithium from sodium and potassium, the arsenic group from the copper group; precipitation methods for the separation of strontium, barium, and lead from calcium and other metals, calcium from magnesium, bismuth from lead; various separations using pyridine and *m*-nitrobenzoic acid; separation of cerium (IV) from thorium, thorium from the rare earths, aluminium from beryllium, cadmium from zinc, and separations within the platinum group.—J. B. B.

An Improved Null-Point Variable Aperture Photoelectric Absorptiometer. J. W. Nicholas. (Metallurgia, 1951, vol. 43, Feb., pp. 95–98). A description is given of an absorptiometer of simple design which can be constructed in the average engineering factory. Permanence in calibration and an accuracy in density readings of 0·001 are to be expected. J. B. B.

The Testing of Steels by Spark Characteristics. V. Rossi. (Rivista di Meccanica, 1950, vol. 1, Oct. 15, pp. 25–26). [In Italian]. This article gives a simple and practical method of testing qualitatively the characteristics of steels by

examining the sparks produced on a carborundum wheel. M. D. J. B.

The Determination of Magnesium in Pig Iron. (Hutnik, 1950, vol. 17, Sept.–Oct., Biuletyn Informacyjny Glownego Instytutu Metalurgii i Odlewnictwa, No. 7–8, p. 29). [In Polish]. Magnesium in pig iron (0·01–0·29%) is determined gravimetrically as magnesium pyrophosphate after the removal of iron (as ferric oxide) by shaking with ether.—V. G.

The Determination of Carbon in Iron, Steel and Iron Alloys by the Barium Hydroxide Method. (Hutnik, 1950, vol. 17, Sept.–Oct.; Biuletyn Informacyjny Glownego Instytutu Metalurgii i Odlewnictwa, No. 7–8, pp. 29–30). [In Polish]. Carbon dioxide obtained on ignition of a sample is absorbed in barium hydroxide. Precipitated barium carbonate is filtered off and determined gravimetrically as barium sulphate.

The Applicability of Spectrographic Methods in Swedish Ironworks. C. G. Carlsson. (Värmländska Bergsmannaföreningens Annaler, 1949, vol. 1, pp. 32–55). [In Swedish]. The majority of the Swedish ironworks have been equipped with spectrographs since 1936. Generally the well-known British makes are preferred and an even more extensive use of spectrographic methods is expected in the future.—B. S. E.

The Determination of Trivalent Chromium in Chromic Acid Plating Baths. F. Ogburn. (Plating, 1950, vol. 37, Nov., pp. 1153–1155). The following method is described. Dilute a portion (x ml.) of the bath, containing about 0·05 g. Cr^{III}, with sufficient water to give a volume of 50 ml. after the addition of the NaOH. Add 4 g. of NaF and add drop-wise, while stirring, 7·5 ml. of 5N-NaOH for each 10 ml. of 2·5M-CrO_3 in the sample. The resultant solution should have a pH of about 5. Heat to boiling and digest on a water bath for 1 hr. and filter through a sintered glass filter. Wash the precipitate of sodium chromic fluoride two or three times with 2% NaF solution. Transfer the bulk of the precipitate to a conical flask containing 100 ml. of water. Dissolve the precipitate left in the filter in 1–2 ml. of conc. H_2SO_4 and then add an equal volume of water and suck the hot solution through the filter and transfer it to the conical flask. Add 20 ml. conc. H_2SO_4 and cool the solution. Titrate the hexavalent chromium, brought down by the precipitate, with ferrous ammonium sulphate (factor f) using ferrous o-phenanthroline as indicator (titre t_1). Dilute the same solution to 200 ml. and oxidize by boiling with 1·5 ml. 0·1N-$AgNO_3$, 5 drops of 1% $MnSO_4$, and ammonium persulphate. A 10% solution of the latter is added in 5-ml. portions till the solution becomes pink or orange. Continue boiling for 10 min., add 2·5 ml. conc. HCl and boil till the colour disappears. Cool and titrate the total chromium with ferrous ammonium sulphate (titre t_2) Cr^{III} g. per litre $= 17·34(t_2 - t_1)f/x$.—J. P.

Determination of Impurities in Electroplating Solutions. XV. Traces of Silver in Copper Plating Baths. E. J. Serfass and P. Burkhead. (Plating, 1949, vol. 36, Dec., pp. 1237–1244). A method is described in which a portion of the copper-plating bath is extracted with a fixed volume of a standard carbon tetrachloride solution of dithizone. The amount of copper in the sample is ample to convert the reagent to the copper compound which has a lavender colour. In the presence of traces of silver, part of this copper is replaced with the formation of silver dithizonate, which has a yellow colour, and the transmittancy of the carbon tetrachloride is increased. The transmittancy is a linear function of the silver concentration in the bath.—J. P.

Determination of Impurities in Electroplating Solutions. XVIII. Traces of Chromium in Copper Plating Baths. E. J. Serfass, Mary H. Perry, and S. Sen. (Plating, 1950, vol. 37, Apr., pp. 389–393). Rapid methods for the determination of chromate and total chromium in copper-plating baths have been developed. These are accurate to 5% if the copper content of the sample is kept between 6 and 26 mg. The aliquot portion of the bath is transferred to a volumetric flask, with a little HNO_3 to oxidize any reducing agents. H_3PO_4 is added to form complex with the ferric ions, and diphenylcarbazide is added to give a red-violet coloured complex with the chromate. The transmittancy of the solution is measured and the amount of chromium present as chromate read from a calibration curve. For the total chromium estimation, the iron is first precipitated with cupferron and extracted with amyl acetate. The solution is fumed with $HClO_4$ and then oxidized with ammonium persulphate in presence of silver ions. The silver is precipitated with HCl which also reduces any oxidized manganese. The solution is centrifuged, the transmittancy of the clear supernatant liquid measured, and the amount of chromium present as Cr+++ and CrO_4'' read from a calibration curve. A modification in which the colorimetric measurement is performed by comparison in Nessler tubes is also described.—J. P.

Determination of Impurities in Electroplating Solutions. XIX. Traces of Nickel in Copper Plating Baths. E. F. Serfass, W. S. Levine, P. J. Prang, Mary H. Perry, and R. B. Freeman. (Plating, 1950, vol. 37, May, pp. 495–499). The copper is removed quantitatively by electrodeposition or by precipitation with tin and the nickel determined absorptiometrically with bromine-dimethyl glyoxime. The electrolysis is performed in H_2SO_4 solution and, since HCN can be removed by boiling such solutions, the method serves also for cyanide copper baths.—J. P.

Modern Equipment for the Laboratory and Industrial Control. Y. Mayor. (Revue of General Exhibition of Laboratory Materials and Industrial Control Apparatus, Paris, 1950: Chimie Analytique, 1950, vol. 32, Nov., pp. 62–64). Materials, methods, and apparatus used in the modern laboratory, and automatic measuring and controlling instruments used in industry, are reviewed.—T. E. D.

General Tendencies in Laboratory Equipment. M. J. Marteret. (International Conference on Analysis and Testing, Société de Chimie Industrielle, 1950: Chimie Analytique, 1950, vol. 32, Nov., pp. 8–10). Many new materials are now available, including special glasses, plastics, synthetic textiles, sintered materials, stainless steels, and the new superrefractories. Standardization and interchangeability of such things as ground joints is important. Automatic measurement and recording are becoming general, and physical and physico-chemical methods are increasingly used. Much precision measuring equipment is now guaranteed by various bodies. Finally, the attainment of very high temperatures, high pressures, etc., has become possible through the use of new techniques.—T. E. D.

The Present Position in Inorganic Analysis. Geloso. (International Conference on Analysis and Testing, Société de Chimie Industrielle, Paris, 1950: Chimie Analytique, 1950, vol. 32, Nov., pp. 13–15). Increased theoretical knowledge, *e.g.*, of the behaviour of ions in solution, is of considerable assistance to the analyst. There are also many new techniques, including those of a physicochemical nature, in use. A few examples are given.—T. E. D.

Physico-Chemical Methods. J. Chedin. (International Conference on Analysis and Testing, Société de Chimie Industrielle, 1950: Chimie Analytique, 1950, vol. 32, Nov., pp. 11–12). Physicochemical methods are increasingly used in research, instead of classical analytical methods. Spectrographic methods, infra-red absorption, potentiometric measurements, polarography, chromatography, and calorimetry are briefly surveyed.—T. E. D.

The Co-Ordination of Analytical Techniques in Industrial Research. R. C. Chirnside, B. S. Cooper, and H. P. Rooksby. (G.E.C. Journal, 1950, vol. 17, Oct., pp. 207–216). The analytical facilities, techniques, and their co-ordination in the laboratories of the General Electric Co., Ltd., at Wembley, are described. Many years' experience has shown that the Analytical Group operates most efficiently as a whole when the following conditions are fulfilled: (1) Full and continuous collaboration between the Group and the other sections of the laboratories requiring its services; (2) the different sections of the Group should themselves act as one unit and, whenever possible, combine their services so as to enhance the value of the results obtained; and (3) opportunities should be available for research in analytical methods in order to equip the Group for meeting new and novel demands for analytical services.—R. A. R.

Report of the Committee of Standardization of Methods of Analysis, of the Spanish Iron and Steel Institute, November, 1948. (Tecnica Metalurgica, 1949, vol. 5, Aug.–Sept., pp. 311–322; Oct., pp. 351–365). [In Spanish]. Work on the determination of manganese is discussed. The oxidation of manganese by sodium bismuthate and the elimination of certain interference effects are described. The ferrous sulphate and sodium arsenite methods are outlined. Methods using ammonium persulphate and potassium chlorate are also given. For the determination of silicon, the sulphuric acid, and the perchloric acid methods are stated. An account

is given of the ammonium persulphate and the potassium permanganate methods for chromium; of the colorimetric method for carbon steels with less than 0·15% of chromium; of the gravimetric, volumetric, and photometric methods for nickel; and, finally, of the methods for the separation of molybdenum.—R. S.

Further Examination of Reproducibility in Chemical Analysis. J. O. Lay. (Journal of The Iron and Steel Institute, 1951, vol. 167, Jan., pp. 42–43). A statistical comparison of results obtained in the evolution of standard chemical and absorptiometric analytical methods for manganese indicates the relationship between standard deviation and reproducibility of results and the contribution of certain factors to the variations found.

Metal Analysis. Part IV—Reproducibility and Repeatability. R. Schmidt. (Metalen, 1950, vol. 4, July, pp. 227–230). [In Dutch]. A study of the general causes of the lack of agreement in results of analyses of identical samples carried out in different laboratories by the same method shows that results obtained from different laboratories at the same time using identical samples and methods give better agreement than results from the same laboratory obtained at different times. The causes of this are discussed. Repeatability is defined as the maximum deviation from the true value which can be attributed to an accidental effect of the uncontrollable factors, in cases where the results are obtained by one observer or a small number of observers using uniform resources. The application of 'randomization' of observations for a correct evaluation of reproducibility is explained.—R. S.

The Application of Radio-Isotopes to Metallurgy. J. Massinon and M.-D.-E. Jonckers. (Bulletin de la Société Royale Belge des Ingenieurs et des Industriels, 1950, July, pp. 129–191) A review is made of the applications to which radioisotopes can usefully be put in metallurgical research. The following applications are discussed: Analysis by means of tracers; autoradiographical study of corrosion, segregation, and defects; equilibrium studies of the distribution of an element between two phases; and study of rates of diffusion followed by tracers. There are 80 references to the literature, and a table of available radioactive isotopes and their characteristics is given.—J. J.

Development, Present State, and Outlook of Spot Test Analysis. F. Feigl. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 1–11). The development of spot test analysis for metals is reviewed; there are 37 references.—J. B. B.

Electro Spot Testing and Electrography. H. W. Hermance and H. V. Wadlow. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 12–34). A sheet of paper impregnated with an electrolyte solution is placed between the surface to be examined and another metal. The metal to be examined is made the anode in an electrical circuit. Ions from the surface of the specimen move into the paper. In electro spot testing these ions are identified by spot tests, and in electrography they show, by means of a reagent applied over the whole paper, the distribution of phases in an alloy, surface condition, inclusions, and porosity in coatings. Full details of the necessary apparatus and many applications are given.—J. B. B.

Instruments for Rapid Metal Identification. R. R. Webster. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 35–48). Commercial instruments used in the rapid identification of metals are described. They are based on the following properties of the metals: Quality of sparks during grinding; radiation from an electric arc with the material to be tested as one of the electrodes; hardness; frictional electricity; thermoelectric effect; magnetic characteristics; and electrical resistance.—J. B. B.

Separating Alloys by Relative Spot Tests. H. Kirtchik. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 49–53). Rapid spot tests can be used to differentiate between small numbers of different steels when all of the types present are known. These tests are used in classifying mixed stock, and to identify incoming materials. Five typical schemes of differentiation are given.—J. B. B.

Rapid Identification of Metal Finishes. A. Lewis and D. R. Evans. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 58–60). A portable kit for the rapid identification of zinc, cadmium, lead, nickel, silver, tin, and chromium metals and plated finishes is described. A small quantity of the metal is electrolytically dissolved into an electrolyte on a filter paper, and the application of reagents to the filter paper produces identifying colours.—J. B. B.

Examination of Plated and Protective Coatings by Electrographic Analysis. N. Galitzine and S. E. Q. Ashley. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 61–68). Practical methods for the application of electrographic analysis to the examination of plated and protective coatings are given, including the detection of pinholes in organic coatings on steel, in zinc on galvanized iror, and in tinplate on copper, and the identification of several coatings plated on a base metal.—J. B. B.

A Field Test Kit and Procedure for Use in the Rapid Identification of Some Nickel Alloys and Stainless Steels. H. B. Lea. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 69–72). A description is given of a simple test kit for the rapid chemical identification of the following metals and alloys: Nickel, Monel metal, Iconel, American Iron and Steel Institute type 316 stainless steel (18–8 Mo), other chromium–nickel stainless steels as a class, and carbon and low-alloy steels as a class.
J. B. B.

Rapid Tests for Identifying Alloy Steels. E. C. Kirkham. (Symposium on Rapid Methods for the Identification of Metals, American Society for Testing Materials, Special Technical Publication No. 98, 1950, pp. 73–76). A simple test kit for the semi-quantitative spot test analysis of alloy steels is described. Approximate percentage indications for chromium, cobalt, manganese, nickel, and molybdenum from spot test reactions, and spark tests for carbon and tungsten allow an experienced operator to classify most alloy steels. Standard steels of known composition must be tested simultaneously.—J. B. B.

On Some Photometric and Sensitometric Determinations in Spectrography. O. Masi and C. Rossi. (Metallurgia Italiana, 1950, vol. 42, Nov., pp. 403–409). A description is given of photometric and sensitivity tests, carried out with standard Zeiss equipment, to establish the applicability of quantitative spectrographical analysis. Particular attention has been paid to the photometer slit width. Two kinds of defects have been found in photos developed in white light, these are defined as 'macro-defects' and 'micro-defects.' Micro-defects for which a simple method of quantitative assessment is developed, may lead to analytical errors amounting to several units per cent. Sensitivity curves of different λ have been determined by means of step filters for plates of similar type but with different emulsion numbers. Sensitivity curves have also been determined for different zones of the same plate and for plates developed after standing for up to 30 days. From the results obtained it is possible to say, in general, that the value of γ is adequately constant.—M. D. J. B.

A Quick Test for Carbon in Steel. Yun-Luan Sun. (Foundry, 1950, vol. 78, Apr., pp. 86–87, 220). The method was based on the principle that the maximum hardness of untempered martensite is directly related to the carbon content irrespective of small amounts of alloying elements present. Rockwell hardness tests were made on a series of water-quenched steel samples of different carbon contents and the resulting values were plotted to show a curve of the variation of hardness with carbon content. This was used, in combination with hardness measurements, to check heats of steel in the foundry. It was evident, however, that this method of carbon estimation would not be applicable to steels having carbon contents above 0·5% where hardness remained constant with increase in carbon. An accuracy of ± 0·02% C was obtained.—E. J. D. S.

Determination of Small Amounts of Vanadium in Steel by Photometric Titration. R. F. Goddu and D. N. Hume. (Analytical Chemistry, 1950, vol. 22, Oct., pp. 1314–1317). The ferrous sulphate–persulphate method for the determination of milligram quantities of vanadium has been improved by a photometric determination of the endpoint. This results

in an increase of the accuracy and precision as shown by the analysis of standard steel samples. High results are obtained if the ratio of chromium to vanadium is more than 10 to 1. If tungsten is separated, other elements common in steel do not interfere.—J. B. B.

Determination of Copper in Steels. J. M. Bermudez de Castro y Mosquera. (Instituto del Hierro y del Acero, 1950, vol. 3, July–Sept., pp. 223–225). [In Spanish]. The Standardization of Methods of Analysis Committee of the Spanish Iron and Steel Institute proposed two methods for rapid analysis of copper and one routine analysis process. The first two are gravimetric. In one, the copper is weighed after being electrolytically separated. In the other, it is weighed as copper oxide. The routine method is volumetric. In it, the copper sulphide precipitated with thiosulphate is evaluated by iodine. The author does not recommend these methods for routine purposes as they take too long and results are too dependent on the operator. The method of Clardy, Edwards, and Leawitt (*see* Journ. I. and S.I., 1946, vol. 153, p. 71A) taking 15 min., with some modifications, is advocated.—R. S.

Colorimetric Determination of Copper in Steel with Rubeanic Acid. W. L. Miller, I. Geld, and M. Quatinetz. (Analytical Chemistry, 1950, vol. 22, Dec., pp. 1572–1573). Details are given of a method for the colorimetric determination of copper in steel with rubeanic acid which does not necessitate the separation of the copper from iron and common alloying elements in steel. Interference from iron is compensated by the use of a reference solution and correction is made for other elements by simple calculation. Results with various standard alloy steels are shown.—J. B. B.

Magnesium Determinations in Nodular Cast Iron—Sampling and Analysis Methods. J. L. Yarne and W. B. Sobers. (American Foundryman, 1950, vol. 17, June, pp. 33–35). A rapid and accurate wet method for analysing nodular iron for magnesium is described step by step. The method covers : (1) Phosphorus separation by dissolving the sample in HCl ; (2) separation of silicon and graphite by filtering ; (3) extraction of most of the iron with ether ; (4) separation of iron and manganese then remaining with ammonium hydroxide and ammonium persulphate ; (5) copper, nickel, and sulphide separations with H_2S ; and (6) the precipitation of magnesium as magnesium quinolate $Mg(C_8H_6NO)_2$ which contains 6·98% Mg, or as magnesium pyrophosphate $Mg_2P_2O_7$. A study of the segregation of sulphur and magnesium with the object of assisting in the sampling of nodular iron is briefly presented. E. J. D. S.

Determination of Magnesium in Cast Iron. J. L. Hague and J. I. Shultz. (Foundry, 1950, vol. 78, Oct., pp. 92–93, 210–211). The method described can be used for checking the magnesium content of standard samples of plain or low-alloy cast iron. It consists of dissolving a 10-g. sample in HCl followed by oxidation with HNO_3, evaporation, and the removal of the iron as the chloride in a continuous ether extractor. The process lasts 3 to 4 hr. Silicon is removed by H_2SO_4 and HF. Magnesium and part of the manganese are then precipitated as phosphates from an ammoniacal citrate solution. The manganese is precipitated as MnO_2 from the solution of the dissolved phosphate precipitate, using ammonium persulphate in a weak acid solution. Magnesium is then precipitated as the phosphate, ignited, and weighed as $Mg_2P_2O_7$, and examined for calcium by the sulphate–ethanol process. An accuracy of about 0·002% Mg for magnesium contents between 0·01 and 0·10% is obtained.—E. J. D. S.

Rapid Determination of the Ash Contents of Combustible Solids by Controlled Combustion in Oxygen. L. Pozzetto. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 156–163). Quality control demands rapid determination of ash contents and indirect methods such as mean density measurements, fractionating in a dense liquid, and opacity to X-rays have been developed. In the direct rapid method desiccation is effected by a current of hot air keeping the coal between 100 and 110° C. and reducing the moisture to 0·5–0·8% in 3 to 4 min. Incineration is in a shallow silica crucible, the oxygen being regulated to keep the temperature below the decomposition point of mineral impurities. The equipment and mode of operation are described.—A. G.

Determination of Ash Content of Coals by Means of X-Rays. P. Belugou and P. Conjeaud. (International Conference on the Preparation of Coal : Revue de l'Industrie Minérale, 1950, vol. 31, Dec., pp. 164–181). By choice of wavelength, and stabilization of incident intensity, the variation of absorption with ash content is sufficient for precise determinations. The absorption is measured by a differential method employing two ionization chambers. The voltage across these is proportional to the ash content and is determined by an electronic voltmeter of high impedance. The accuracy is close to 0·5%.—A. G.

HISTORICAL

From the Past of the Ironworks in the Ural. S. Pluszczewski. (Hutnik, 1950, vol. 17, Nov.–Dec., pp. 393–401). [In Polish]. An historical survey of the foundation and development of ironworks in the Ural district and details of present expansion of the metallurgical industry are given.—V. G.

Early Ironmaking in North-East Scania. P. Johnsson. (Blad för Bergshandteringens Vänner, 1949, No. 4, pp. 297–301). [In Swedish]. In 1948 remnants of smelting furnaces and a workshop were discovered in a Scanian forest. Bog iron ore was used as a raw material for weapon manufacture some four centuries ago in these areas.—B. S. E.

The Great Century of Iron Making in the Swedish Province of Värmland. J. Furuskog. (Värmländska Bergsmannaföreningens Annaler, 1948, vol. 1, pp. 39–58). [In Swedish]. With the development of the Värmland ironworks during the XVIIth century as background, some glimpses of contemporary social conditions are given in this address delivered at the centenary celebrations of the Värmländska Bergsmannaföreningen.—B. S. E.

Some Notes on a Piece of Iron Found at Petterstorpet, North-East Scania. H. Uhrus. (Blad för Bergshandteringens Vänner, 1949, No. 4, pp. 302–305). [In Swedish]. Analytical data of the above finding prove that it is derived from bog iron ore.—B. S. E.

Henry le Chatelier, His Life, Career and Works. G. M. Chaudron. (Revue de Métallurgie, 1951, vol. 48, Jan., pp. 10–18).

Extensions of the Work of Henry le Chatelier. R. Perrin. (Revue de Metallurgie, 1951, vol. 48, Jan., pp. 19–31).—A. G.

Notes on the History of Steels. A. Leroi-Gourhan. (Techniques et Civilisations, 1951, vol. 2, No. 7, pp. 4–10). A comparative description is given of various types of swords and daggers of various ages from different parts of the world, with particular reference to irregularities and the designs on their blades.—J. J.

History of Iron Manufacture. L. Barreiro. (Boletin Minero e Industriel, 1951, vol. 30, Feb., pp. 59–77). [In Spanish]. A Spanish version of the Latin poem 'Ferrum' written in 1717 by R. P. Xavier de la Sante is given. The poem is followed by a glossary and a chronological index to events in the iron and steel industry from 4000 B.C. to 1938.—R. S.

The History of Pig Iron Manufacture in Alabama. B. C. Colcard. (American Iron and Steel Institute : Blast Furnace and Steel Plant, 1951, vol. 39, Feb., pp. 223–226). Alabama's first blast-furnace was built in 1815 and by 1860 seven small stone furnaces had been erected. During the Civil War 12 new blast-furnaces were built but the industry was devastated by its end. In 1873 a new type of furnace was introduced having an iron shell and regenerating stoves giving blast temperatures of 600 to 800° F. In 1880 the iron industry boomed, production increasing from 69,000 to 1,185,000 tons in 1900. Since 1900 13 new furnaces have been added and production in 1950 was 4,000,000 tons.—E. J. B.

Trip Hammers in the Sauerland. K. Lange. (Metal Treatment and Drop Forging, 1951, vol. 18, Feb., pp. 86, 87). This is a short historical account of the development and decline of the ancient craft of trip hammer forging in the Ruhr valley region of Germany. The wooden water-driven hammers were first built about 600 years ago.—P. M. C.

Hammersmith—America's First Successful Iron Works. E. L. Bartholomew, jun. (Metal Progress, 1950, vol. 58, Dec., pp. 875–876). A XVIIth century ironworks in Massachusetts is being excavated. There is a reconstructed ironworks house, and also moulds of slag, while current investigations indicate details of the blast-furnace, as a preliminary to further restoration.—E. T. L.

Pittsburgh of Barotseland. M. Hubbard. (Steelways, 1951, vol. 7, No. 2, March, p. 6). A primitive African guild in Barotseland on the Zambesi river makes iron as it did at the birth of the Iron Age. The process is very briefly described. D. H.

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The Steel Company of Wales. A. J. K. Honeyman. (Bulletin of the Institution of Metallurgists, 1951, vol. 3, No. 1, pp. 27–33). The history of the Steel Company of Wales is really the history of the steel trade in South Wales, for it was formed by the four great steel companies of South Wales pooling certain of their resources and knowledge. The history of iron and steel making in South Wales is traced from the early XVIIIth century to the great expansion in 1947 under the post-war Steel Development Plan.—D. H.

Development of the Tinplate Industry in Great Britain. W. E. Hoare. (Bulletin of the Institution of Metallurgists, 1951, vol. 3, No. 1, pp. 4–26). The author gives a survey of the development of the tinplate industry in Great Britain. The factors influencing the beginning of such an industry in South Wales during the early XVIIIth century are outlined. The paper deals with the progress made in the practical, scientific, economic, and commercial fields and ends with a short chronology of the tinplate industry.—D. H.

A Czech Manuscript on the Art of Founding. M. F. Pisek. (Techniques et Civilisations, 1951, vol. 2, No. 7, pp. 11–20). A description is given of the contents of a remarkable XVIIth century document in Czech. It was written by Kricka, and is concerned with the manufacture of guns, pumps, and bells. J. J.

Commemorating Dimitrij Konstantinovič Černov. L. Jeníček. (Hutnické Listy, 1951, vol. 6, Jan., pp. 2–5). [In Czech]. This is a brief review of the life and work of the Russian scientist D. K. Černov who died 30 years ago. His contribution to the advancement of metallurgy is described and a complete list of his work is given.—E. G.

ECONOMICS AND STATISTICS

The Swedish Foundry Industry—Its Present Position and the Future. I. Forslund. (Gjuteriet, 1949, vol. 39, No. 4, pp. 49–63). [In Swedish]. Different aspects of the foundry industry and its rôle in the Swedish national economy are explained. Future trends and prospects are outlined.—B. S. E.

Changes in Swedish Steel Exports. H. Dahlerus. (Blad för Bergshandteringens Vänner, 1949, No. 2, pp. 233–249). [In Swedish]. The tendency to export more manufactured high-quality steel products even to markets outside Europe is said to be continuing.—B. S. E.

The Rôle of Steel in the Marshall Plan. E. G. Frisell. (Blad för Bergshandteringens Vänner, 1949, No. 1, pp. 215–219). [In Swedish]. The government four-year plan implies an increase in the Swedish steel production from one million tons to 1·54 million tons by 1952–53. The development will cost about 500 million kronen and require 2800 men. The export quantity of high-quality steel can be doubled.—B. S. E.

The Iron and Steel Industry in the Six Year Plan. J. Borejdo. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 279–286). [In Polish]. The six-year plan for the Polish iron and steel industry is outlined.—V. G.

The Organization of Enterprises in the Iron and Steel Industry of Western Europe. F. Hellwig. (Stahl und Eisen, 1951, vol. 71, Mar. 29, pp. 321–327). The organization of combines, both horizontal and vertical, in the Belgian, French, and Luxemburg iron and steel industries, including ore, coal, and coke, is discussed.—J. P.

Stainless is Growing Apace. R. E. Paret. (Metal Progress, 1951, vol. 59, Jan., pp. 58–61). Production has increased from 180,000 to 800,000 tons since 1939, in America. There is an outline of the principal uses of stainless steel, and an estimate of future demands. The availability of chromium and nickel is fairly satisfactory. The scarcity of the element columbium may be offset by the use of tantalum or titanium, so that the supply position is limited only by the competing requirements of other users.—E. T. L.

The Basic-Bessemer Process and the Economic Development of the Grand Duchy of Luxembourg. C. Hemmer. (Revue Technique Luxembourgeoise, 1951, vol. 43, Jan.–Mar., pp. 31–36). A historical survey is made of the development of the Luxembourg steel industry and its social implications following the discovery by Thomas of the basic-Bessemer process. This enabled the local high-phosphorus ores to be used for steelmaking. In 1862 the consumption of minette ore rose to 20,000 tons and in eight years to over 368,000 tons. In 1949 the pig-iron production was 2,372,000 tons and steel 2,271,000 tons. The basic slag produced is readily marketable, 500,000 tons being exported in 1948.—B. G. B.

The Development of the Metallurgical Industry in Holland after 1945. F. G. van Riet. (Metalen, 1950, vol. 5, Dec., pp. 70–73). [In Dutch]. The broad trends of the steel fabricating, steel and iron casting, non-ferrous smelting, and powder-metallurgy industries are briefly surveyed.—R. S.

Mining and Metallurgical Problems in Spain in 1949. (Metalurgia y Electricidad, 1950, vol. 14, Dec., p. 58). [In Spanish]. Output figures are given for iron ore, fluorspar, pyrites, coal, aluminium, zinc, tin, lead, and steel.—R. S.

Operations M-1 and M-2. J. Alzina Caules. (Acero y Energia, 1951, vol. 8, Jan.–Feb., pp. 15–18). [In Spanish]. This is a commercial note on the Spanish government's plans for developing exports of metallurgical products from Northern Spain.—R. S.

Spanish Iron and Steel Problem and the New National Plan. M. Rojas Morales. (Boletin Minero e Industriel, 1951, vol. 30, Jan., pp. 7–15). [In Spanish]. This is a survey of the Spanish iron and steel problem. National steel consumption is detailed and the possibilities of increased production in Spain are discussed. It is considered that a single integrated plant with 500,000 tons annual capacity is desirable. The metallurgical possibilities of the Biscay, Catalan, and the south-eastern and north-eastern regions are considered. Details are given of Devonian and Silurian iron ores and of coal consumption. There is a tendency to use active mixers with open-hearth production which eliminates additions of phosphates, permits wider limits in iron analysis, lower coke consumption, less ferro-alloy, and flexibility in the use of scrap. Details are given of washed coal analysis and coke analysis. Finally, the proposed new plant installations are enumerated and production figures are estimated for the 1955, 1958, and 1960 stages of the national plan. Total capital involved will be 1,613,000,000 pesetas.—R. S.

Electro-Metallurgy Plan for Peru. J. Sanz y Diaz. (Metalurgia y Electricidad, 1951, vol. 15, Feb., pp. 44–46). [In Spanish]. Only the main tasks of the plan are mentioned—development of anthracite production; use of iron ore of Marcona (several hundred million tons); and hydro-electric schemes.—R. S.

MISCELLANEOUS

The Organization of Research in French Iron and Steelmaking. G. Delbart. (Bulletin de la Société Royale Belge des Ingenieurs et des Industriels, 1950, Series A, No. 1, pp. 10–22). A description is given of the relationship of Institut de Recherches de la Sidérurgie (IRSID) with the French iron and steel industry, and of the interior organization of the former. A description is also given of the new laboratories and premises being constructed for IRSID.—J. J.

Graphic Representation of Time Lost in Waiting in the Iron and Steel Industry. A. Zalewski. (Hutnik, 1950, vol. 17, Sept.–Oct., pp. 299–304). [In Polish]. The use of this graphic representation in operational research and management is discussed.—V. G.

Graphic Representation of Time Losses in the Iron and Steel Industry. A. Zalewski. (Hutnik, 1950, vol. 17, Nov.–Dec., pp. 438–444). [In Polish]. Methods of graphic representation of time losses in the iron and steel industry and their usefulness are discussed.—V. G.

Guiding Principles for Economy in Steel Management. A. Stupnicki. (Hutnik, 1950, vol. 17, Sept.–Oct., 1950, pp. 305–308). [In Polish].

Industrial Human Relations in the Light of Work Physiology. H. Spitzer. (Stahl und Eisen, 1951, vol. 71, Apr. 12, pp. 393–399). The value of physiological studies in obtaining the most economic expenditure of human energy in industry is discussed.—J. P.

Methods and Incentives towards Economical Working. H. Spitzer. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 28–32). Various methods designed to ensure economical working and their results are discussed. These include disciplinary measures, instruction, competition, awards and bonuses, and ensuring best working conditions. Some examples from the field of fuel economy are given.—J. P.

Radiant Heating: Applications in Steel Works and Foundries. F. H. Slade. (Iron and Steel, 1950, vol. 23, Aug., pp. 355–356). The author details the advantages of radiant heating for factories and describes its application in foundries and steelworks, giving as an example the radiant heat installation

by Richard Crittall and Co., Ltd., in the light castings foundry of Newton Chambers, Ltd.—G. F.

Measurement Technique. B. Chierego. (Rivista di Meccanica, 1950, vol. 1, Nov. 15, pp. 9–11). [In Italian]. A review is given of the fundamental principles involved in the measurements of length, weight, and volume. Modern industrial and laboratory techniques are described and a classification of measuring equipment is given.—M. D. J. B.

Instrumentation for Metallurgy. R. R. Webster. (Metal Progress, 1951, vol. 59, Jan., pp. 87–92). This is a review of recent advances in the use of instruments. There is an outline of the use of pyrometers, pressure controllers, immersion thermometers in the open-hearth process, and mention of the use of the spectroscope with the Bessemer process. In soaking pits temperature is measured by radiation thermopiles, and also in heating furnaces. Dimensions of products can be measured by X-ray absorption, and carbon content of steel is found rapidly by magnetic analysers. Other elements are analysed by colorimetric techniques, or the direct-reading spectrograph. Ultrasonics and the electron microscope are mentioned.—E. T. L.

Television in Industry. J. A. Good. (Iron and Steel Engineer, 1951, vol. 28, Mar., pp. 107–110). The author describes the possible uses television could be put to in the iron and steel industry. It is suggested that a large number of pictures of gauges and recorders could be brought to one central point from which it would be possible to keep in constant touch with distant parts of the works. General information on television equipment is given together with brief specifications for electrical and mechanical parts.

M. D. J. B.

Ninety Years of the Verein deutscher Eisenhüttenleute. E. Herzog. (Stahl und Eisen, 1951, vol. 71, Jan. 4, pp. 1–8). The development of the Verein deutscher Eisenhüttenleute is illustrated by reference to the work of members who were famous for their industrial, technical, and scientific achievements.—J. P.

The Program and Achievements of the Institute of Technological Research at São Paulo. F. J. H. Maffei. (Mineração e Metalurgia, 1950, vol. 15, Nov.–Dec., A.B.M. Noticiario, vol. 4, Nov.–Dec., pp. 173–178). [In Portuguese]. The activities of the following sections of the above research station are surveyed: Standards and specifications, process control, analysis, mechanical testing, and raw materials.

R. S.

BOOK NOTICES

FREEMAN, H. G. "*Fachwörterbuch Werkzeuge.*" 1. Teil. "*Deutsch-Englisch.*" 8vo, pp. 319. Essen, 1950: Verlag W. Girardet. (Price DM 24.–).

This latest volume of Freeman's specialized technical dictionaries covers the field of hand and machine tools, gauges, and measuring instruments. In order to minimize reference to other technical dictionaries when reading German publications on these subjects, the most common terms in the allied fields of manufacturing processes, driving mechanisms, gears and screw threads, and materials and their surface or heat-treatments, are included. It does not claim to be complete within these subsidiary fields, but strictly within the scope of its main subjects the English (or, more frequently, American) equivalent of a German word will seldom be sought in vain. Compound words and phrases are entered both alphabetically and under their key word (for example, all the different types of file are listed again under "*Feile*"), which facilitates reference although adding to the bulk of the dictionary.

The dictionary itself is preceded by 22 pages of conversion factors and tables for conversion between metric and British or American units.—H. R. MILLS

HESS, M. "*Paint Film Defects—Their Causes and Cure.*" 8vo, pp. xvii + 544. Illustrated. London, 1951: Chapman and Hall, Ltd. (Price 50*s.*)

This is a scholarly work, which may be regarded as a major contribution to paint technology, and will form a valuable source of reference. The author has set out to classify the various defects that can develop in paint films. The field to be covered is large, as it embraces all types of paint, all the purposes for which paints are used, and all the materials, iron or steel, non-ferrous metals, stone, concrete, plaster, etc., to which paints are applied.

The contents are divided into four main chapters. These deal, respectively, with faults developing during storage of the paint, during its application (whether because of faulty technique or of defects in paint composition), shortly after application, and with defects arising during the service life of the painted article. Each chapter is subdivided into numerous sections relating to specific problems. There are nearly 150 of these and in them the author discusses such questions as the settling of paints in containers, lack of hiding power, the toxic effects of poisonous paint materials, faults developing in radiator paints, the painting of iron and steel, the swelling of films by moisture absorption, and the resistance of paints to petrol and mineral oils. Copious reference is made throughout to the scientific and technical literature, and in most cases he suggests suitable remedies for the trouble concerned.

It would be beyond the power of any single reviewer to follow the author critically into each individual problem. It will suffice to say, on the one hand, that he is a paint technologist of repute and an esteemed member of the Oil and Colour Chemists Association, so that his views must carry considerable weight. On the other, it may be said that, with a few unimportant exceptions, what he has written about the painting of iron and steel would find general acceptance. The main value of the work is that it brings a vast mass of knowledge and experience into a classified and systematic whole. The labour and assiduity needed to complete such a task must have been enormous and the results are enhanced by the fact that, through his long association with the paint trade, he is able to throw light on many of the problems involved.

If a few minor criticisms may be permitted, it might be felt that in places the author has not been sufficiently selective. For example, some of the material in the section on the painting of iron and steel, although of considerable general interest, has little direct bearing on protection by painting. Moreover, not unnaturally, the author has retained a tendency to think and express himself in his native tongue. This occasionally leads to a rather involved sentence or to the use of the wrong word; for example, towards the bottom on page 279 the German word "Zunder" has been rendered as "tinder" instead of, in the present context, "millscale" or "oxide." As a rule these verbal points are of no great moment and the author's meaning is clear. On page 425, however, when he states that fouling usually occurs when a vessel is in port and is worse on the port side, some confusion may be caused. Presumably the word "port" is used the second time to denote the side facing the quay rather than as the antithesis of "starboard."

There are a few printer's errors and I have been unable to find Fig. 42B.—J. C. HUDSON.

KELLS, L. M. "*Calculus.*" 8vo, pp. xii + 508. Illustrated. London, 1951: George Allen and Unwin, Ltd. (Price 28*s.*)

This book is written to teach calculus to young technologists. It is a recent American text which has gone into a second American edition and is now published in Great Britain by what looks like photographic copying. The author is Professor of Mathematics at the United States Naval Academy and he has presumably designed the book as a teaching one for his own use primarily. In consequence it is especially suitable for students with practical and pictorial minds, who appreciate the concrete application rather than the generalized abstraction of the mathematician. This field of teaching the academic side of science to those taking a technology course is ill supplied with textbooks in Great Britain and it is therefore a useful addition to the current range.

The text starts from an assumed knowledge of elementary algebra and then introduces differentiation as a limiting process with emphasis on rates with reference to time.

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However, the more conventional representation of a derivative as a tangent to a curve is prominent. The first five chapters develop this work with both pictorial application and an admirable substrata of mathematical rigour. The most interesting feature of the whole book is the sly way the author does introduce a rigorous outlook with his copious illustration and applications—a most praiseworthy attitude. A large number of new examples and exercises are given, with answers, throughout.

The next three chapters introduce the idea of integration, first as an inverse operation to differentiation and then as a limiting sum, such as an area. Three more chapters cover the differentiation of trigonometric and logarithmic functions, completing some 240 pages and about half the book.

The next chapter is devoted to vectors, starting from a simple basis of displacement, and this extra chapter, like later ones on infinite series and ordinary differential equations, definitely reflects the sketchy, omnibus teaching of the technologist. This second part of the book is devoted to the more isolated aspects of the subject and the author usefully emphasizes the value of tables of integrals. His Appendix 1 is in fact a table of 159 integrals, but he omits to give any reference to more extensive collections. Indeed, the whole book is written in a completely self-contained form, just as so many generations of school textbooks have been. No further guide of any kind is mentioned and an undiscerning student might well suppose there was nothing more to the subject. The book concludes with some four-figure tables of logarithms and trigonometric functions which are deplorable. They are badly printed, badly laid out, give no differences, use varying type faces and, as the greatest enormity, are carefully arranged so that the two pages of any one table are on opposite sides of the paper. These are a disgrace to a useful book. Finally, there is an adequate index.

This book is therefore a teaching text suitable for younger students and, more particularly, technological students. It is lengthy, 500 odd pages, and is not crisp enough for private study. But it has virtues in its new and detailed applications of the theory and in its underlying note of mathematical rigour. Its vices are in its American tone, which act like a hiccough on the British reader, and in its details of printing and the numerical tables.—H. HERNE

PHYSICAL SOCIETY. "*Reports on Progress in Physics.*" Vol. XIII, 1950. 8vo, pp. 424. London, 1950: The Physical Society. (Price 50*s.*)

The subjects covered in this volume include the investigation of eye movements, infra-red solar spectroscopy, radio astronomy, planetary atmospheres, the propagation of shock waves on fluids, and two aspects of nuclear physics. Only one paper will be of interest to the ferrous metallurgist, it is "Ferromagnetism: Magnetisation Curves." In this, Prof. E. C. Stoner, of the Physics Department of the University of Leeds, reviews studies made in this field since 1934. It is a lengthy paper, of nearly 100 pages, and deals with the magnetization of single crystals, domain structure, the analysis of magnetization curves, and, finally, magnetic materials. Among those of technological interest are the non-metallic materials, 'ferrites,' of general formula $MO.Fe_2O_3$, and the 'micropowder' magnetic materials. These latter are made up of particles in the range $3\text{–}4\cdot5 \times 10^{-6}$ cm., values consistent with the theoretical estimates of size for single-domain particles. The appropriate magnetic quantities of iron and iron–cobalt micropowders are comparable with those of 'Alnico' and suggest possibilities for use as permanent magnets.

Useful surveys are also presented in this paper on the effects of cold-rolling in producing preferred orientation in iron–silicon alloys, and on the present knowledge of the magnetic properties of iron–nickel alloys.—J. P. S.

ROTHERHAM, L. A. "*Creep of Metals.*" (Physics in Industry). 8vo, pp. 80. Illustrated. London, 1951: Institute of Physics. (Price 15*s.*)

Hitherto the Institute of Physics has only included in the 'Physics in Industry' series, lectures and symposia arranged by the Institute. Recently, however, the Board invited a number of distinguished authors to contribute monographs on special branches of applied physics, and this is the first of them. It is a very short monologue, but is so well written and illustrated that it deals remarkably adequately with the whole subject of creep..

The characteristics of the creep curve are described in the introductory chapter and the author then goes on in chapters 2, 3, and 4 to describe crystalline flow, the metallographic features of creep, and grain-boundary creep respectively. In chapter 5 the author describes transient creep and points out that it is similar to crystalline plasticity in that large numbers of atoms are involved in the glide process. Chapter 6 deals with steady-state creep which involves the arrangement of only a few atoms. Tertiary creep, *i.e.*, the period of accelerating creep towards the end of the technical creep test, is covered by chapter 7. Chapter 8 (Development of Creep-Resistant Alloys) is probably the most interesting chapter in the whole monograph, and it may well serve as a general guide to any metallurgist or physicist seeking to develop better creep-resistant alloys. There is one small error in this chapter which the author may have already noticed, and that is where niobium and columbium are mentioned together as if they were two different metals.—J. FERDINAND KAYSER

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Steel Products Manual.*" Section 17. "*Low Carbon Steel Flat Wire.*" 8vo, pp. 59. New York, 1951.

AMERICAN IRON AND STEEL INSTITUTE. "*Steel Products Manual.*" Section 30. "*Carbon Spring Steel Flat Wire.*" 8vo, pp. 70. New York, 1951.

BASTIAN, L. H. "*Metalworking Lubricants. Their Selection, Application, and Maintenance.*" Pp. 364. New York: McGraw-Hill Book Co., Inc. (Price $6)

BRITISH STANDARDS INSTITUTION. B.S. 78: 1938. Addendum No. 1: April 1951. "*Weights of Special Castings.*" 8vo, pp. 27. London: The Institution. (Price 3*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 1719: 1951. "*Classification of Covered Electrodes for the Metal-Arc Welding of Mild Steel and of Medium-High-Tensile Steels of Welding Quality.*" 8vo, pp. 17. London: The Institution. (Price 2*s.* 6*d.*)

BRITISH STANDARDS INSTITUTION. B.S. 1249: 1951. "*Cast Iron Columns for Street Lighting.*" 8vo, pp. 8. London: The Institution. (Price 2*s.*)

CHESTER, D. N. "*The Nationalised Industries.*" An Analysis of the Statutory Provisions. Second Revised Ed. 8vo, pp. 93. London, 1951: George Allen and Unwin, Ltd. (Price 7*s.* 6*d.*)

DU MOND, T. C. "*Engineering Materials Manual.*" Pp. 200. 8vo, New York, 1951: Reinhold Publishing Corporation. (Price $4.50)

HOGAN, W. T. "*Productivity in the Blast Furnace and Open-Hearth Segments of the Steel Industry* 1920–1946." Pp. 150. New York: Fordham University Press. (Price $4)

KINGSTON, W. E. "*The Physics of Powder Metallurgy.*" Pp. 404. New York, 1951: McGraw-Hill Book Co., Inc.

LEE, J. A. "*Materials of Construction for Chemical Process Industries.*" 8vo, pp. 468. Illustrated. New York, 1950: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 55*s.* 6*d.*)

LOCATI, L. "*La Fatica dei Materiali Metallici.*" Pp. 333. Milan, 1950: U. Hoepli. (Price 1600 lire)

MONTANEL, P. "*Métaux.*" Pp. 40. Paris, 1950: Librairie Gauthier-Villars. (Price 250 fr.)

PASCOE, SIR EDWIN H. "*A Manual of the Geology of India and Burma.*" Third edition, revised and largely re-written. Vol. I. 8vo, pp. xvi + 483. Illustrated. Calcutta, 1950: Government of India Press.

ROBERSON, E. C. "*The Industrial Gas Turbine.*" Pp. 162. Illustrated. London: Temple Press, Ltd. (Price 8*s.*) 6*d.*

TIPPETT, L. H. C. "*Technological Applications of Statistics.*" Pp. ix + 189. New York, 1950: John Wiley and Sons, Inc. (Price $3.50)

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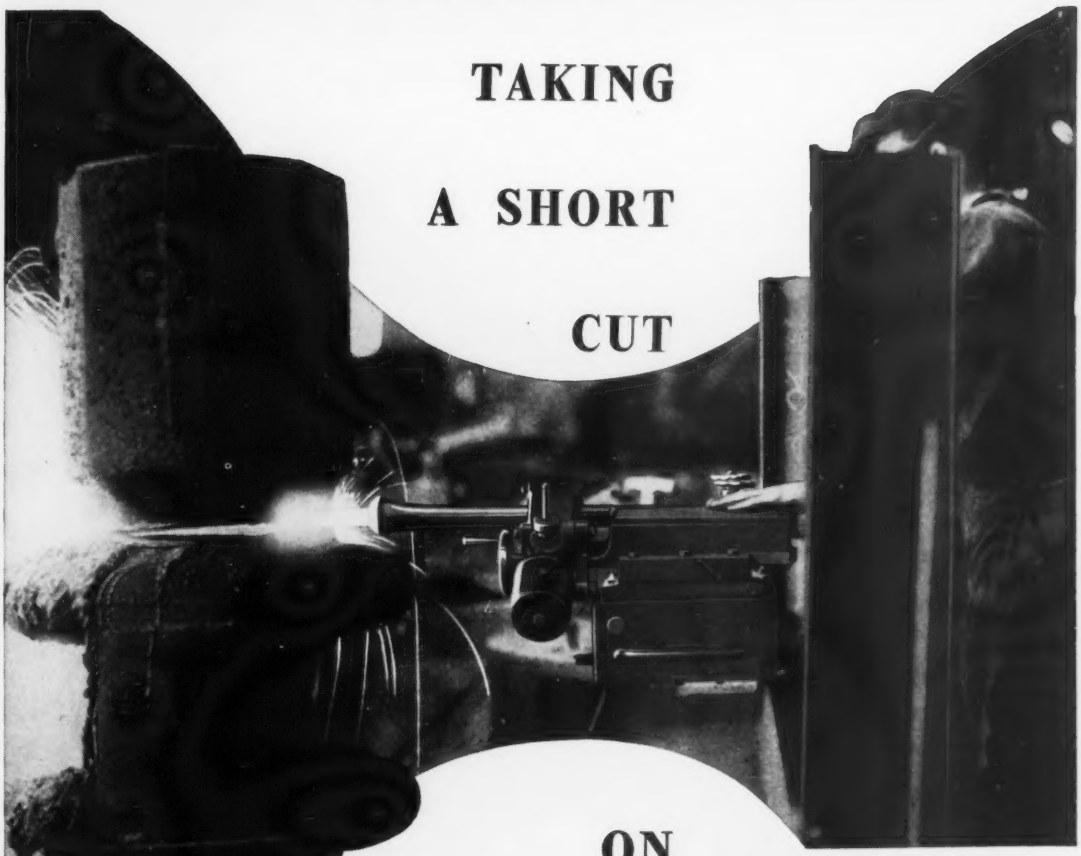

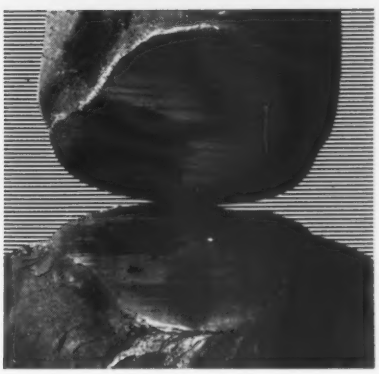

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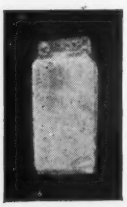
COLVILLES  STEELS

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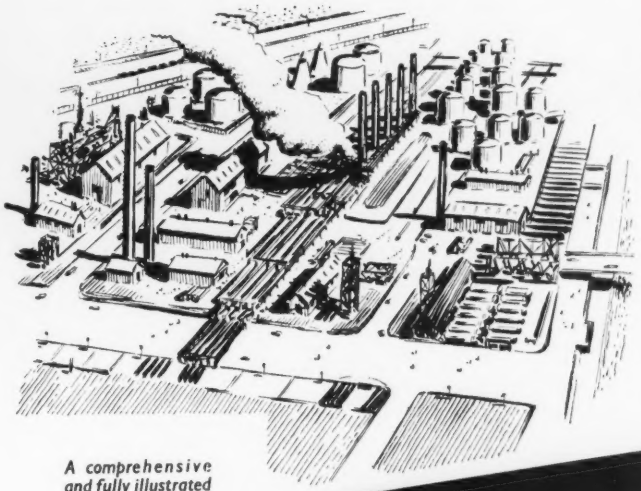

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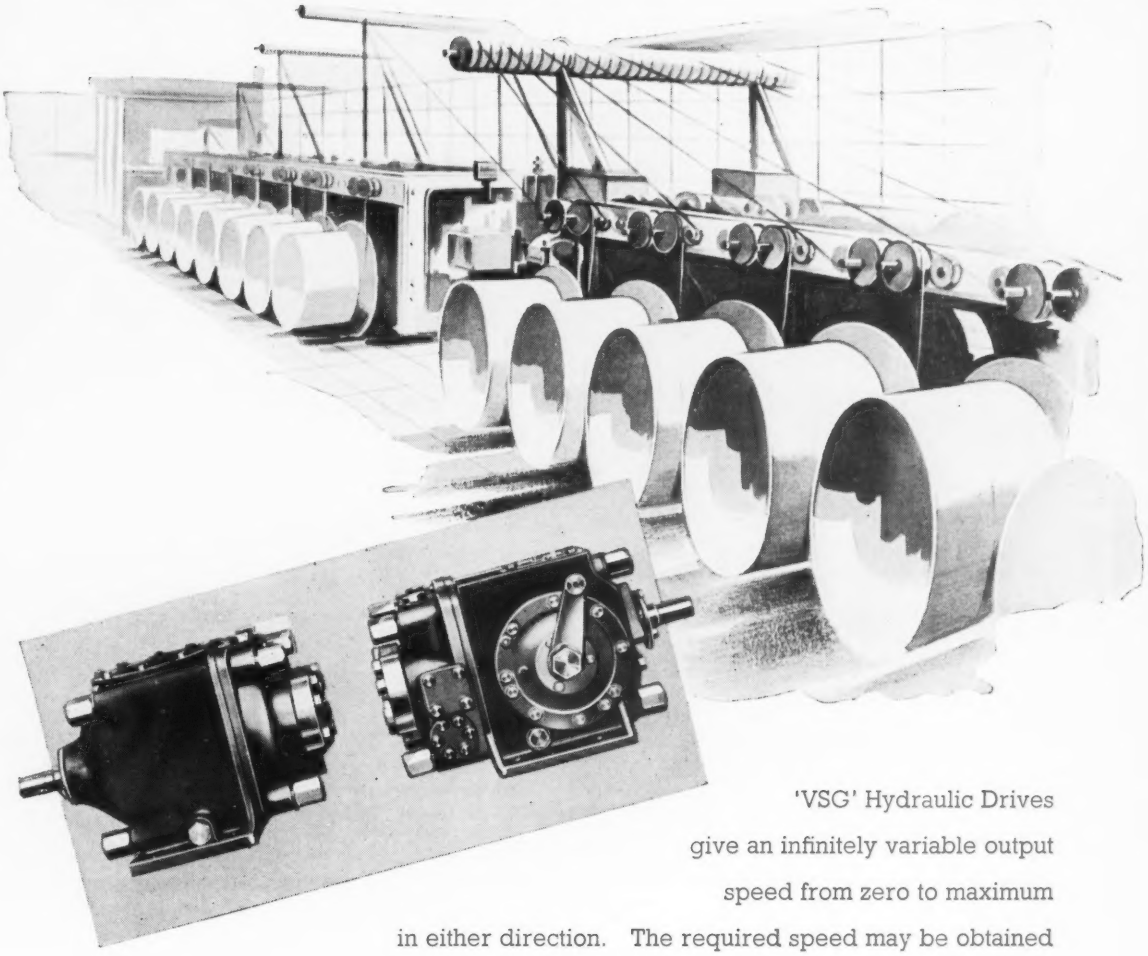

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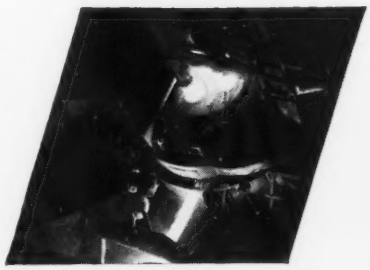
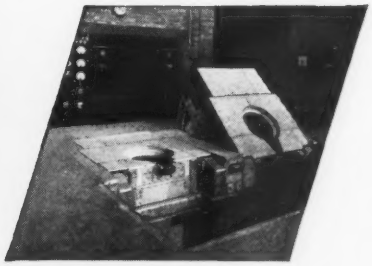


Arc furnace for steel melting



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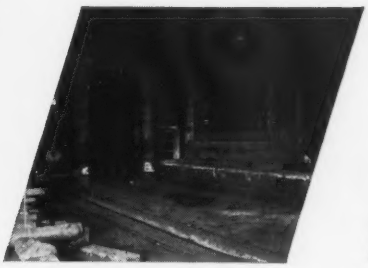
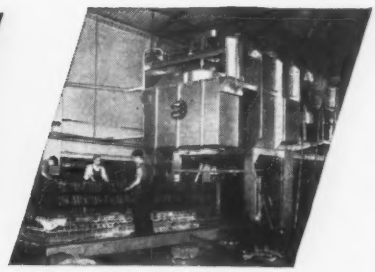
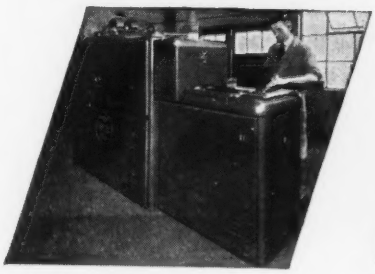


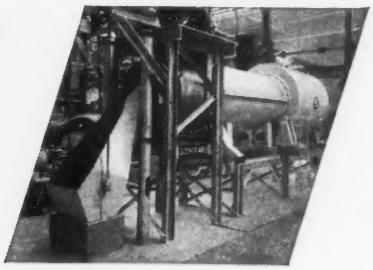
Bogie hearth furnaces for ordnance



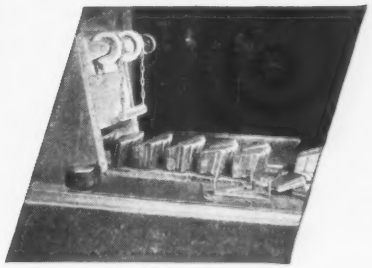
Elevator furnace for annealing malleable castings (track links)



Shaker hearth furnace for small steel articles



Rotary drum furnace for cartridge case annealing



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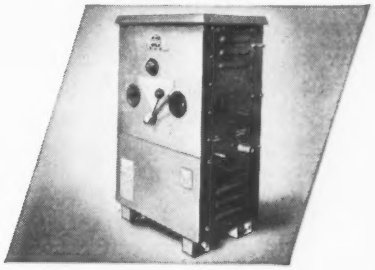

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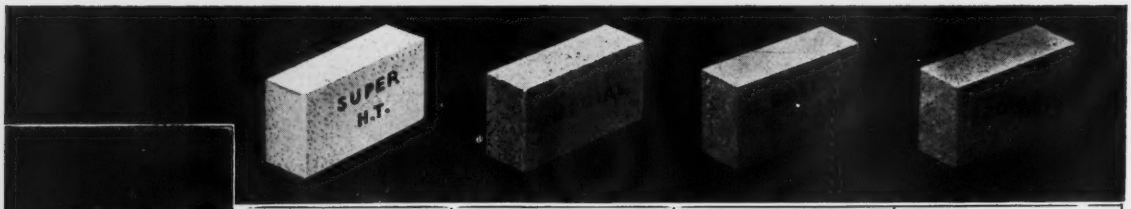

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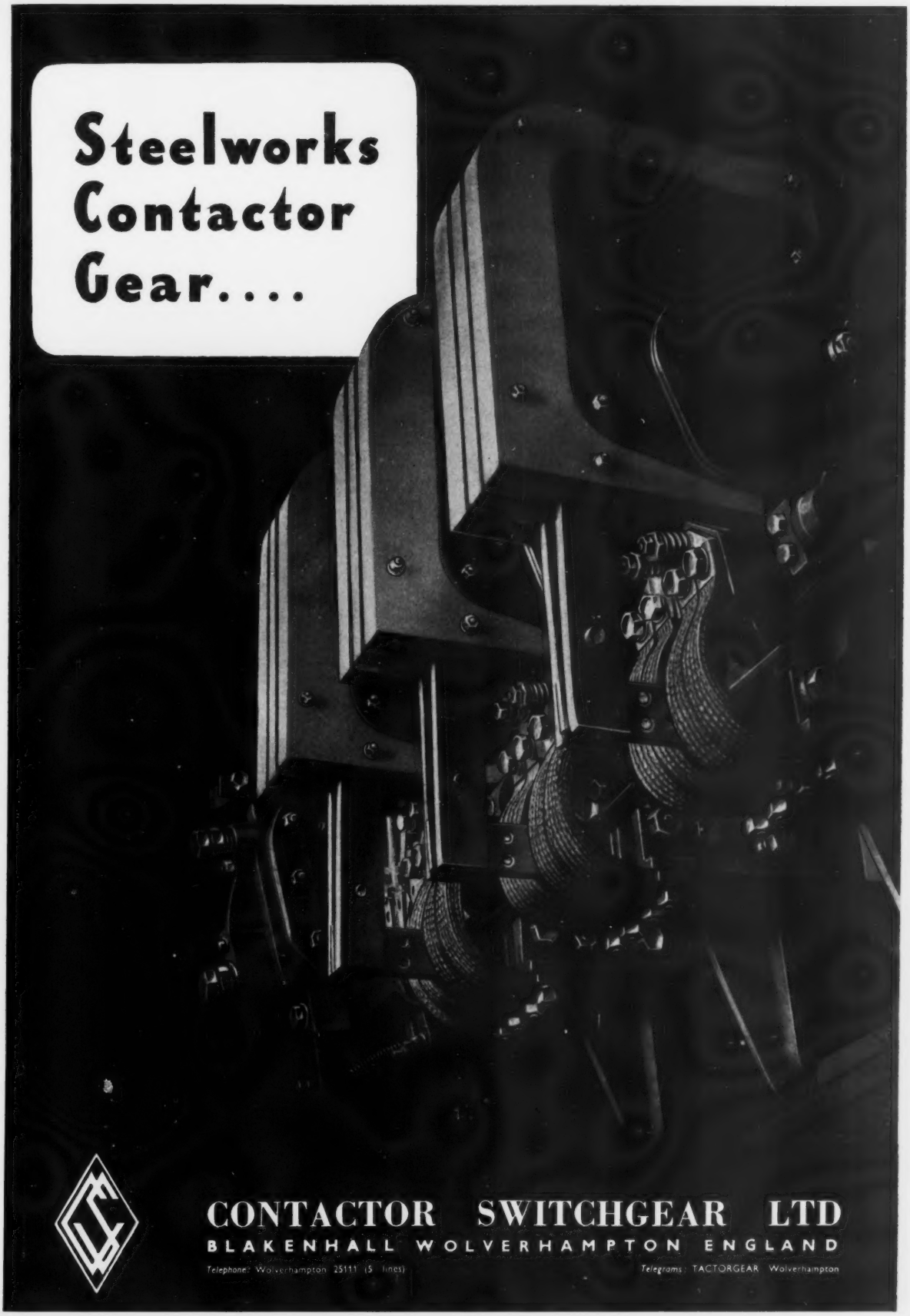
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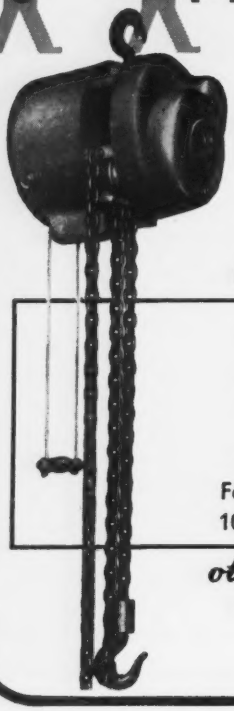

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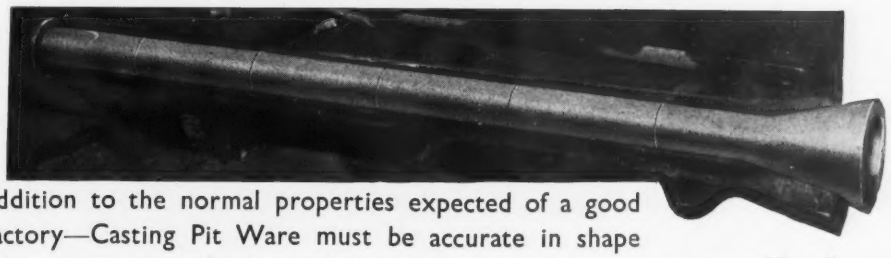

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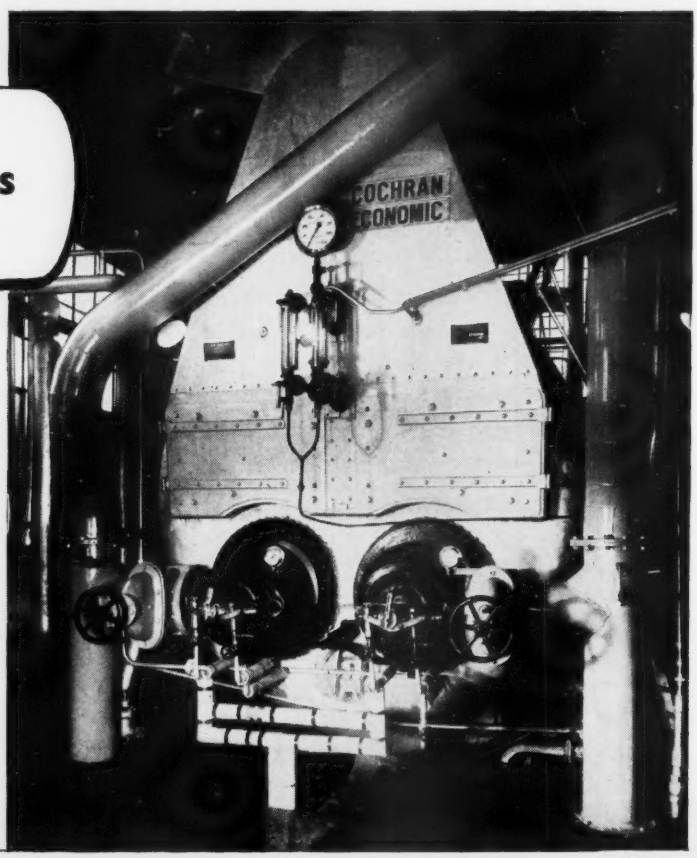

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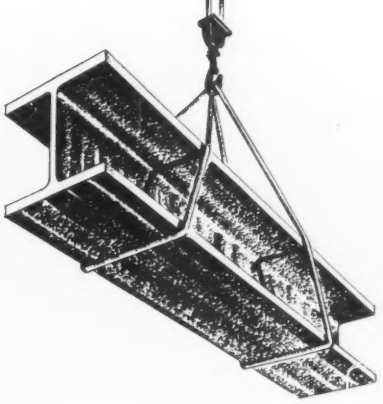

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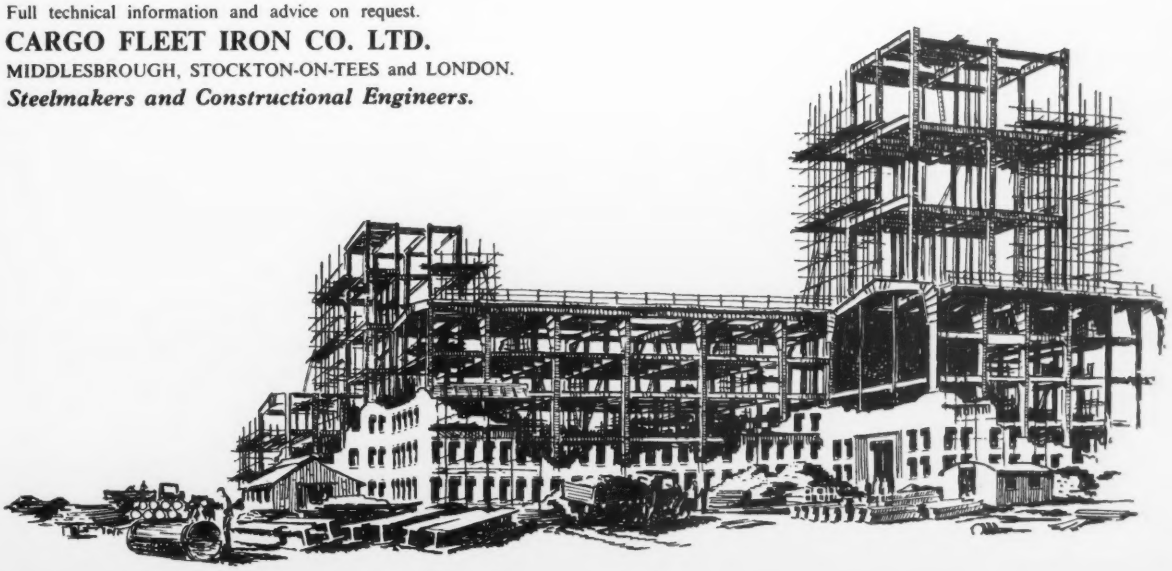

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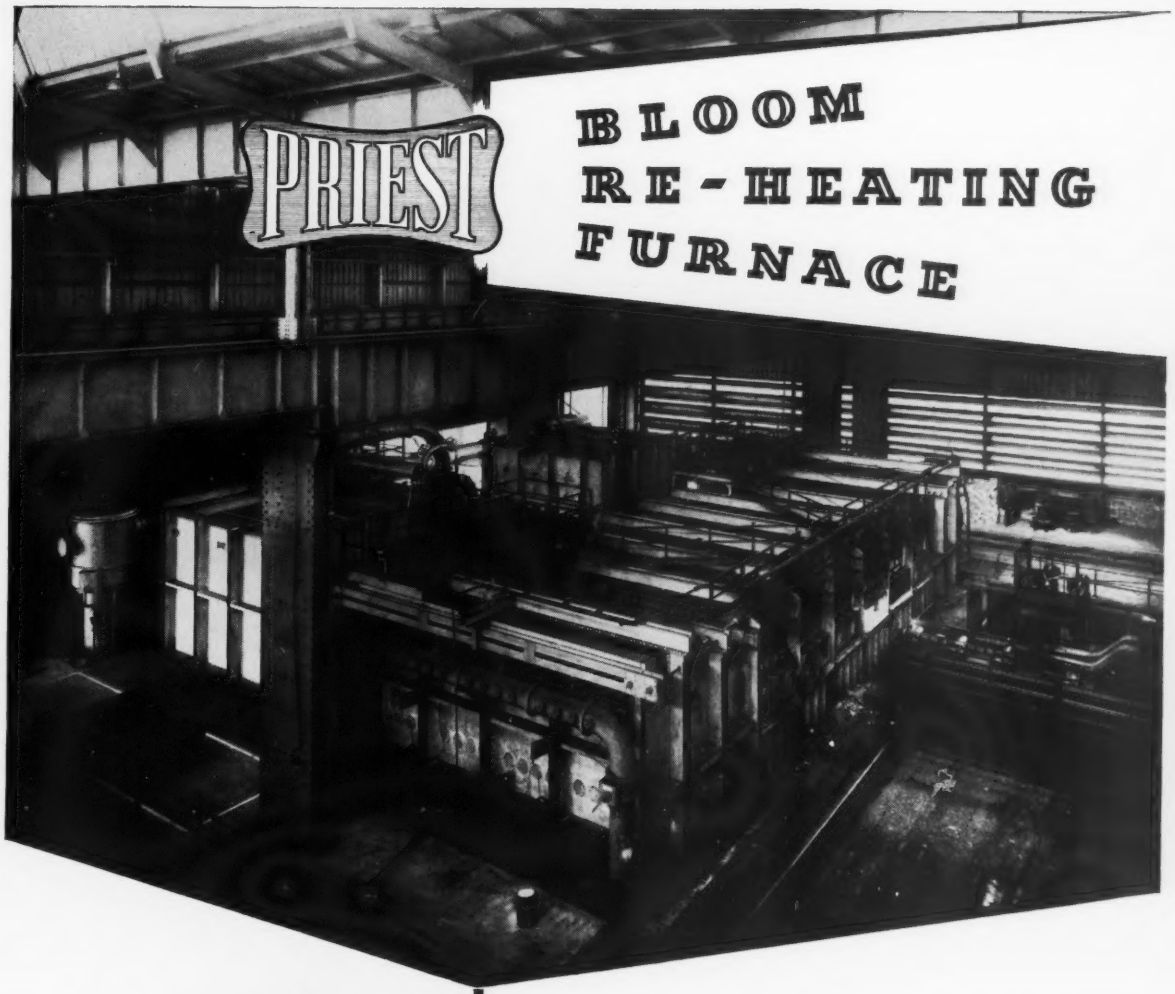

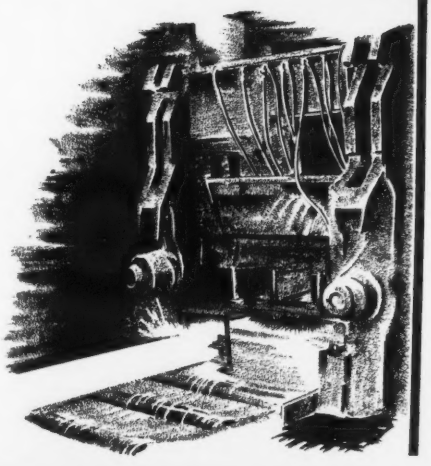

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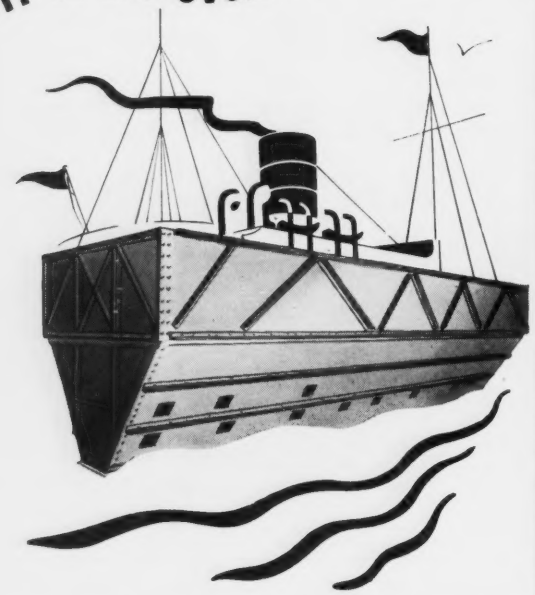

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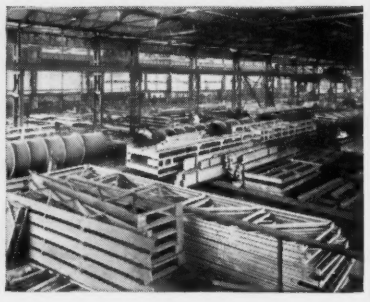

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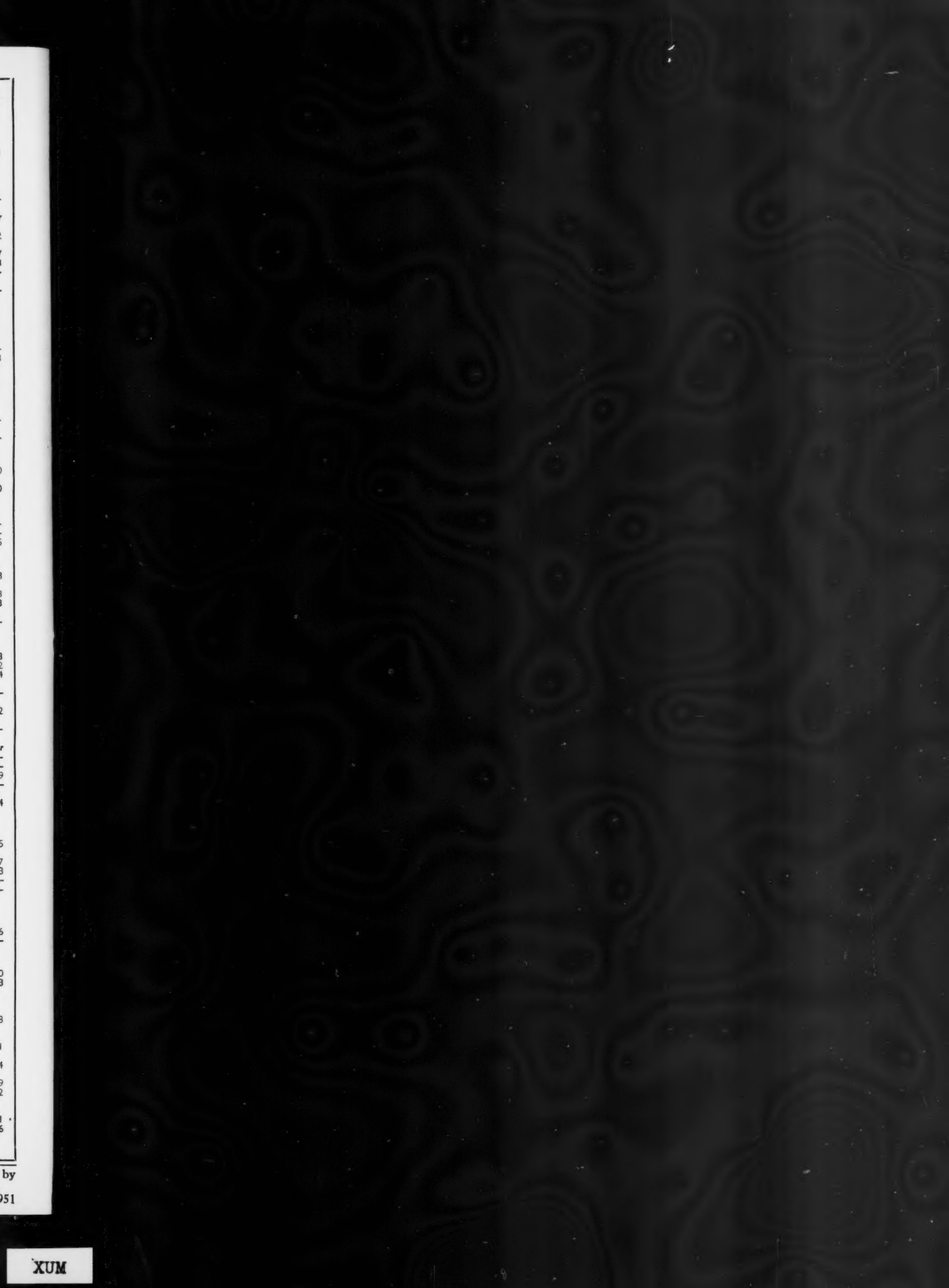

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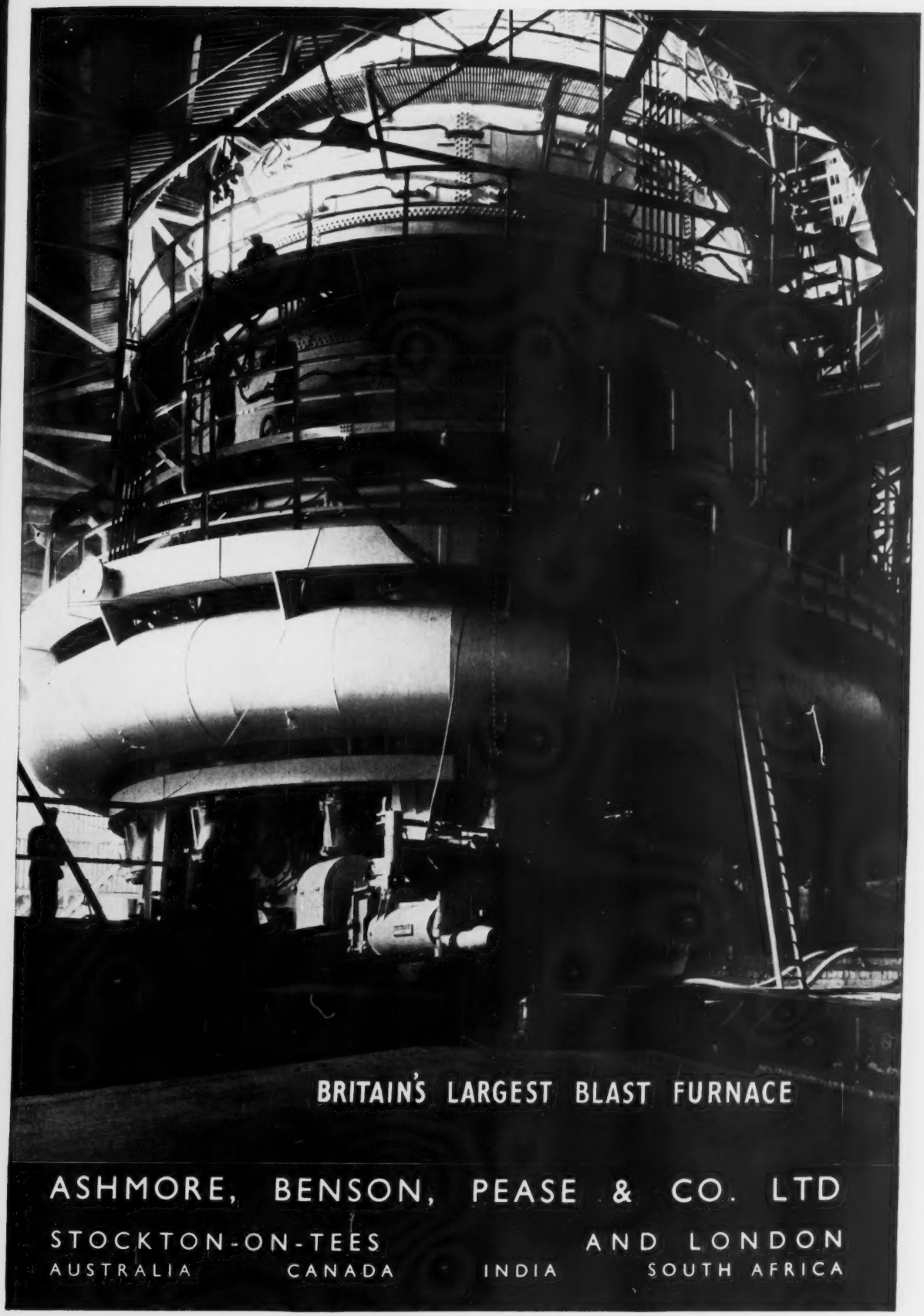
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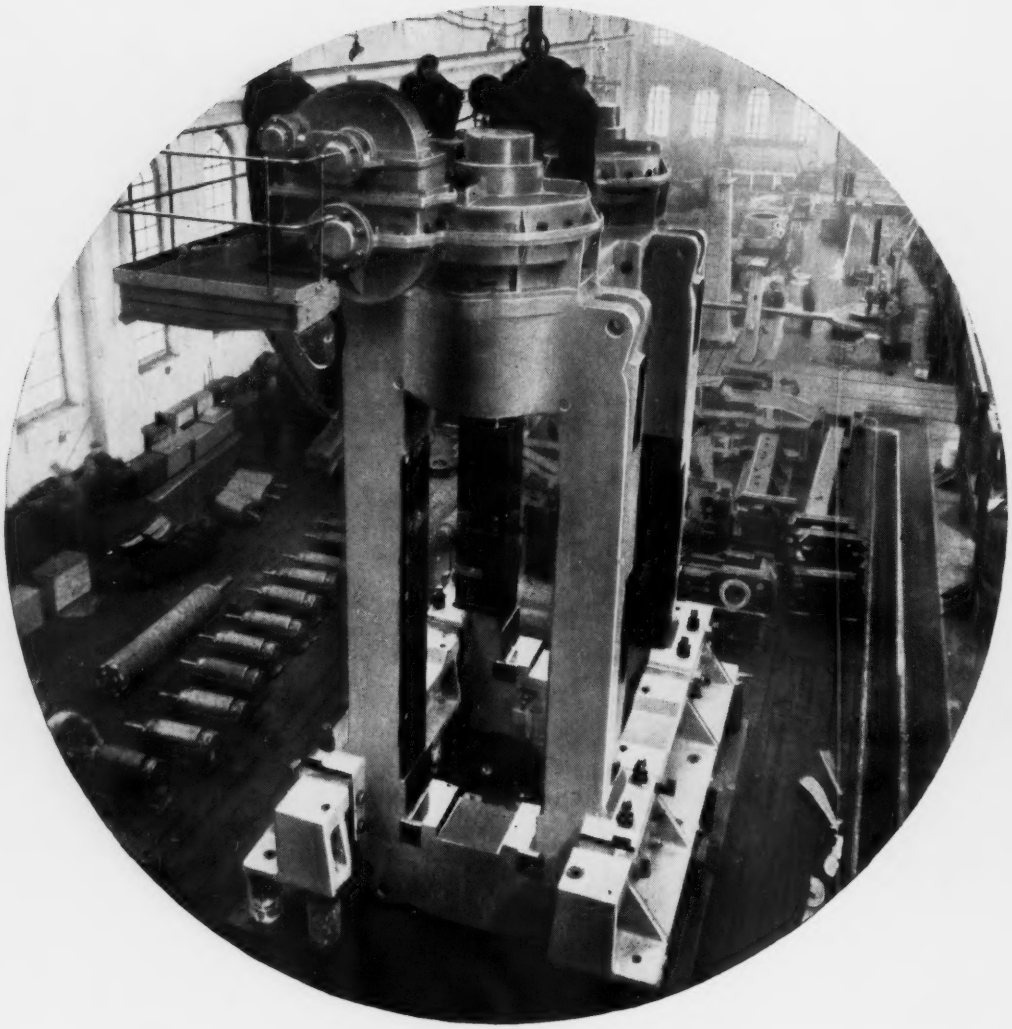

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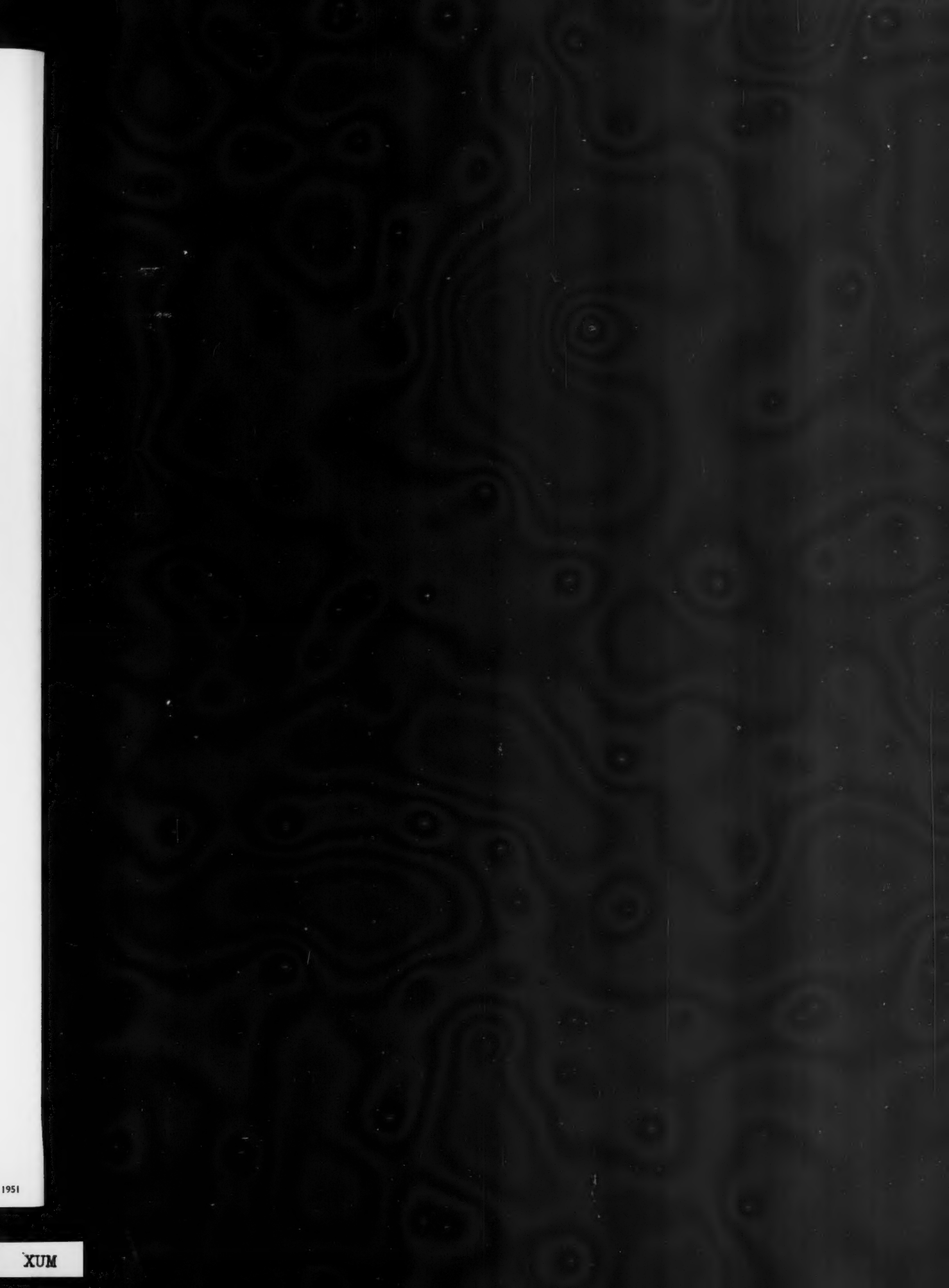
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